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SOIL REACTING FORCES ON CULTIVATOR SWEEPS

by

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ABSTRACT

Various cultivator sweeps and their manner of movement in the soil were studied by measuring the soil reacting forces in three different field soils. A split plot factorial design with the soils in main plots and the other factors in subplots was used. A multi-component sensor was used for the acquisition of the data which was statistically analyzed. The results indicated that lift height and edge thickness of the sweeps affected the draft and vertical force. The effect of lift height was associated with the changes in the angle of shear surface, whereas, the response of edge thickness was attributed to the compaction effects. A low lift sweep with thin edge was considered beneficial with regard to energy and operation.

The zone of influence or mass of soil tilled and disturbed, was found to be dependent on depth of cut, speed of travel and whether or not the sweep was overlapped. The increase in the force accelerating the soil with an increase in the tool velocity, partially accounted for the increase in the draft and the decrease in the vertical force with the increasing tool velocity. The magnitude of lateral reacting force of the overlapped sweeps was found to be a function of depth of cut and speed of travel. In general, the resultant of all the soil reacting forces passed near the tip of sweep indicating the area of maximum pressure. The resultant for a shallow depth did not intercept the sweep and no mechanism could be advanced to account for this.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PHOTOGRAPHIC PLATES

CHAPTER 1

INTRODUCTION

Throughout history advances in tillage technology have contributed to increasing yields and improving the quality of agricultural foods. Plowing is a very ancient practice which is still considered fundamental for seedbed preparation. The most popular implement for cultivation is the mold board plow. Improvements in tillage implements have continued and today, in addition to mold board plows, one can purchase several types of cultivators each designed for specific field conditions and requirements. A cultivator equipped with sweeps is an example.

The importance of optimizing tillage operations for improving tillage tool design is illustrated by the large volume of soil tilled each year. For example, in the United States more than 250 billion tons of soil are stirred or turned each year. To plow this volume of soil requires 500 million gallons of petroleum costing over $100 million (15). If improved tool design and operation could decrease the draft by even a small fraction, the saving would be appreciable. Increasing fuel costs dictate that efforts be continued to improve tillage efficiency.

The cultivator with sweeps is a widely used implement in the prairie provinces of Canada. Consequently, an investigation of the effects of certain variables, such as the shape of the tool and its orientation, on the soil reacting forces, is of great importance. An investigation of soil-sweep forces will contribute to improvement in design and operation of the cultivator.

CHAPTER 2

LITERATURE REVIEW

2.1 Tillage Objectives.

More than a century ago Jethro Tull, an English farmer made the gross assumption that tillage improved soil productivity by breaking the individual soil particles into small fractions. Today, a more rigorous concept of tillage objectives is required. Kepner et al (15) list many, the most important being to:

- form a desirable soil structure for a seedbed,
- control weeds,
- manage plant residues,
- minimize soil erosion by altering surface conditions.

The sweep causes little soil inversion which is an advantage when trash should be left on the surface, or mixed with the top few inches of soil, to reduce erosion. This tool cuts the roots of weeds and pulverizes the soil like a mold board plow.

2.2 Soil-Tool Relationships.

Gill and Vanden Berg (8) suggest a generalized force equation which aids in classifying the variables involved in a soil-tool relationship, that is,

$$F = f(Ts, Tm, Si) \qquad 2.1$$

where F = forces on tool to cause movement

Ts = tool shape

Tm = manner of tool movement

Si = initial soil condition.

The three factors, initial soil condition, tool shape and manner

of its movement, define the soil manipulation. Of the three factors, the designer is largely concerned with the tool shape. The user, however, may vary the depth or speed of operation and will use the tool in a variety of initial soil conditions.

2.3 Factors Affecting Soil Reacting Forces.

2.3.1 Soil Conditions

(a) Bulk density and moisture content.

Generally dry bulk density is considered to be an indication of the soil strength and therefore the draft. The soil strength also depends on the moisture content of the soil. Barnard and Cooper (3) report a direct relationship between the draft and bulk density of a soil and the same relationship has been confirmed by others (27,29). Whereas, the effect of moisture content on the soil strength, unlike that of bulk density on soil strength, is not a simple relationship. For example, Vomocil and Chancellor (28) report that, for a soil with moisture contents greater than permanent wilting percentage, the strength, as indicated by the angle of internal friction, increases to a maximum and then decreases as the soil dries. Similarly an investigation by Fox et al (7) indicates that the energy required to break a given clod size was a complicated function of moisture content. The energy required was minimum at 17% and 24% moisture contents. It appears that the principal role of water in soil strength changes with the moisture content.

The effects of moisture content and bulk density on the strength of a soil, however, are interdependent. For example, Panwar and Siemens (18) report that, at a density of 87.1 lbs/ft^3 the shear strength was 26.5 psi at 16.5% moisture content decreasing to 10.5 psi at 28.1% moisture content, whereas, at the density of 74.5 lbs/ft^3

the shear strength changed only slightly at various moisture contents.

(b) Soil texture and other factors.

Texture is one of the important soil factors affecting the soil reacting forces of tillage tools. Gordon (9) indicates that the energy requirement for tillage is less for pulling plow disks in a sandy loam soil as compared to that in a clay soil and a similar observation has been reported by Rowe and Barnes (21). The reason given by these authors is that a sandy loam soil is low in shear strength as compared to that of a clay soil. Telischi et al (27) describe that the draft of a tillage tool is a power function of the clay content of a soil. Telischi et al, conclude that the clay content of a soil is the main textural element causing resistance to the motion of a tillage tool. They advocate, however, that the effect of clay content on the draft depends on the amount of moisture in the soil, that is, there is an interaction between the clay and moisture contents with respect to the draft.

In addition to the clay and moisture contents, other factors affect the soil reacting forces in a field soil. For example, Baver et al (2) cite a study by Keen and Haines that, an annual application of 14 tons of manure per acre caused a reduction in draft. They also obtained a reduction of 6 to 13 percent in draft with a heavy application of chalk. Further, Baver et al (2) advocate that roots of live vegetation increase the draft during plowing because of the force required to cut the roots. Telishci et al (27) conclude that, in addition to clay content, the chemical composition of colloids, apparent specific gravity, organic matter and live vegetation are pertinent soil factors in tillage studies.

2.3.2 Tool Shape.

Tool shape is characterized by the macro, micro and edge shapes. The configuration of macro shape (gross surface) includes many variables such as the approach angle (1), attachment angle (1), suction (1), and lift height. Lift height is the vertical displacement of the rear edge of the tool relative to the leading edge. Sirohi and Reaves (23) suggest that the energy requirement for a tillage tool varies directly with the lift height. Krause (16) calculated that 12% of the total energy is required to lift the soil, however, he did not indicate his method. Gill and Vanden Berg (8) report studies by Soehne and Kawamura who have shown direct relationships between draft and lift height of simple tools. Kawamura (8) suggests that the increase of lift decreases the angle of the failure plane with the horizontal. The decreased angle results in a larger failure surface and hence a greater force to cause failure. Soehne and Kawamura (8) suggest further work to analyze the effect of lift height on soil forces.

The roughness or microshape of a surface over which soil slides influences frictional forces and hence the scouring. The microshape depends on the degree of polish, the number and depth of scratches and other irregularities. Gill and Vanden Berg (8) indicate that the frictional resistance at the soil-tool interface may be such a small portion of the total draft, that even with large changes in microshape or friction, only small changes in total draft will occur. Microshape may affect scouring which in turn alters the macroshape of the tool; that is, consideration of microshape of a tool is limited to whether the tool scours or not.

The thickness of the leading edge of a tool affects the total draft for the reasons not obvious. Gill and Vanden Berg (8) quote Soehne who believes that the leading edge of tool cuts the soil and the cutting resistance of soil is small, becoming important only when stones or roots are present. In the absence of such situations, the cutting component of the total force might be considered negligible. On the other hand, Gupta and Pandya (10) developed equations directly relating draft and thickness of a tool. The direct relationship without any mention of the cutting phenomenon, suggests that there is some reason other than cutting, responsible for the relationship. The leading edge compacts soil upwards, ahead and downwards contributing to the draft and vertical reaction. The compaction ahead and downwards will increase with the thickness of the leading edge, increasing the draft and decreasing the vertical reaction downwards.

2.3.3 Manner of Tool Movement.

The manner of tool movement refers to variables such as depth of cut, speed of travel and extent of overlap. Reed (20) reports that increasing the depth of tillage from 6 to 8 inches increased the draft by 14 to 16 percent. A direct depth-draft relationship has been reported by Harrison and Reed (11) and Shankar (22). Reason being that the area of shear surface increases with the depth of cut and hence the draft.

The effect of speed on draft has been of great interest to researchers. Reed (20) cites a study by Ashby and Glaves, who reported an increase of 8.6 percent in draft with an increase of speed from 2.5 to 3.25 mph. Telischi et al (27) advocate that as speed increases

the draft also increases, depending on the moisture content of the soil. Though there are some investigations (5,13) in which draft was independent of speed, the speeds were too low to have any practical significance. In general, the draft of a tool increases with the increase in speed but there is some disagreement as to the cause. Rowe and Barnes (21) concluded that the increase in the draft with an increase in speed was primarily due to increased shear strength of soil, whereas, Krause (16) advocates that acceleration of soil is responsible for the increase in power with speed. Hendrick and Gill (14) advocate that soil acceleration can account for only a fraction of the increased draft, and that the increase is mainly due to changes in soil strength with speed. Hendrick and Gill (14) conclude that soil strength is rate dependent unless clay and moisture contents are low.

Some researchers have studied the effect of speed on the vertical reaction. Gordon (9) and Wismer and Luth (29) report that a tool tends to penetrate more readily with an increase in speed, indicating that vertical reaction increases (downwards) as the speed increases. The authors do not account for the relationship indicating a need for further investigation.

When two tools are operated in the proximity to one another, interference may occur, that is, the operation of at least one of the tools is influenced by the presence of the other. The effect of tool interference or overlap was studied by Chisholm et al (4). The results indicate that the draft of an overlapped tool is decreased. The authors discuss that the decrease in draft appears to be due, at

least partly, to formation of a trench behind the overlapping tool. This trench facilitates the flow of soil around the overlapped tool and therefore the draft is decreased. It seems more likely that the decrease in the draft of the overlapped tool is associated with the simple fact that the overlapped tool encounters a portion of tilled soil having a lower soil strength.

2.4 Summary.

The literature review indicates two points clearly. Firstly, researchers were mainly interested in the draft measurements and they ignored that the vertical and lateral forces have their individual effects on the operation of tillage tools and implements. Secondly, the soil-sweep system has not been studied in detail and would benefit by the measurement of the three soil forces for common variations in the shape of the tools.

CHAPTER 3

EXPERIMENTAL DESIGN AND PROCEDURE

3.1 Factors and Their Levels.

Equation (2.1) was considered in the selection of pertinent variables, namely, initial soil condition, tool shape and manner of tool movement, for their effects on the soil reacting forces of a sweep.

(a) Soil conditions.

Three sites were selected to ascertain the effect of soil conditions with respect to the soil reacting forces of a sweep. Additional sites were not included because of the time limitation and the doubtful gain of information. Soil samples were collected from the sites and analyzed using the hydrometer method. The textures of the three sites/soils were silty clay loam, clay loam and clay. During the experiment bulk densities and moisture contents were determined to futher define the condition of the soils. The moisture contents were calculated according to American Society of Agricultural Engineers Standards S-358. The bulk densities were measured using gamma ray transmission equipment as detailed by Soane et al (24). The depths for the measurements of bulk densities and moisture contents coincided with the depths of tillage in the experiment.

(b) Tool Shape.

The shape of a sweep shovel is characterized by many variables such as approach angle, suction, width, lift height and edge shape. Some of these variables were included in the study as noted below.

Gill and Vanden Berg (8) indicate that the thickness of the leading edge of a tool affects both the draft and vertical reaction.

[illegible]

To investigate the nature and magnitude of the effect on soil reacting forces of a sweep, edge thickness was included at two levels of 1/4" and 5/16". These thicknesses were selected because of their common use in the Western Canada and Alberta. Additional levels of the edge thickness could not be included because they were not available commercially with the other factors.

As noted previously in section 2.3.2, Soehne and Kawamura have reported a direct relationship between draft and lift height of a simple tool, however, the available literature does not indicate the effect of lift height on either the vertical or the lateral reaction of a tillage tool. Therefore, lift height was included at two levels to investigate its effects on all the three soil reacting forces of a sweep. The lift heights selected were 1 1/64" and 1 1/4". The reason for the selection of only two lift heights was their availability with the two thicknesses selected earlier.

Two sets of 16 inch wide sweeps, each set with the above selected edge thicknesses and the lift heights, were purchased and identified as makes, as each make was sold by a different company. The purpose to include the make at two levels was to compare the soil reacting forces of the sweeps coinciding in geometries, but sold by different companies. Some dimensions of the sweeps are given in Appendix 1.

(c) Manner of tool movement.

The effect of depth of tillage on soil reacting forces is well known, however, the depth was included at two levels because there may be significant interactions. The usual tillage depth for a cultivator in Western Canada is three to four inches and therefore three and four inch depths were included in the study. The effect

of speed on the draft of a tool has been studied, while the effect on the vertical and lateral reactions to the tool is not clear. For investigating the effect of speed on all the three soil reacting forces of a sweep, the speed was included at two levels. As the normal travel rates are between three and six mph, these two speeds were included. Only one previous investigation (4) included the effect of overlap on soil reacting forces, therefore, overlap was included at two levels, that is, without overlap and with overlap. An overlap of two inches was used because of the common practice of using 16 inch sweeps on 12 inch centres.

3.2 Experimental Design.

A split plot factorial design was considered appropriate because of virtual impossibility of randomizing soils/sites. Soils were in the main plots with the other six factors (Table 1) randomized in the subplots. Considering the limitation of time and a suggestion by McKibben et al (17), three replicates were considered appropriate. The order of experiment and the form of the analysis may be noted in the Appendices 2 and 3.

3.3 Facilities and Equipment.

The experiment was conducted using the workshop and field facilities of the Department of Agricultural Engineering, University of Alberta. The equipment used can be seen in Plate 1. The multi-component sensor (Plate 2) has been described in detail by Harrison (12). The sensor was mounted on a tractor (MF-135). The equipment in the van (Plate 3) is the data acquisition equipment.

3.4 General Arrangements.

A sweep, having the same size as those of the sweeps used for

TABLE 1: FACTORS AND LEVELS SELECTED FOR THE STUDY.

Factor/Level	Description
Soil 1	Silty clay loam
Soil 2	clay loam
Soil 3	clay
Make 1	-
Make 2	-
Low lift	1 1/64"
High lift	1 1/4"
Thin	1/4"
Thick	5/16"
Depth of cut	3"
Depth of cut	4"
Velocity of travel	3 mph
Velocity of travel	6 mph
Without overlap	-
With overlap	2" overlap

PLATE 1: GENERAL SETUP OF THE EQUIPMENT.
A: VAN WITH DATA ACQUISITION EQUIPMENT.
B: TRACTOR WITH MULTI-COMPONENT SENSOR.

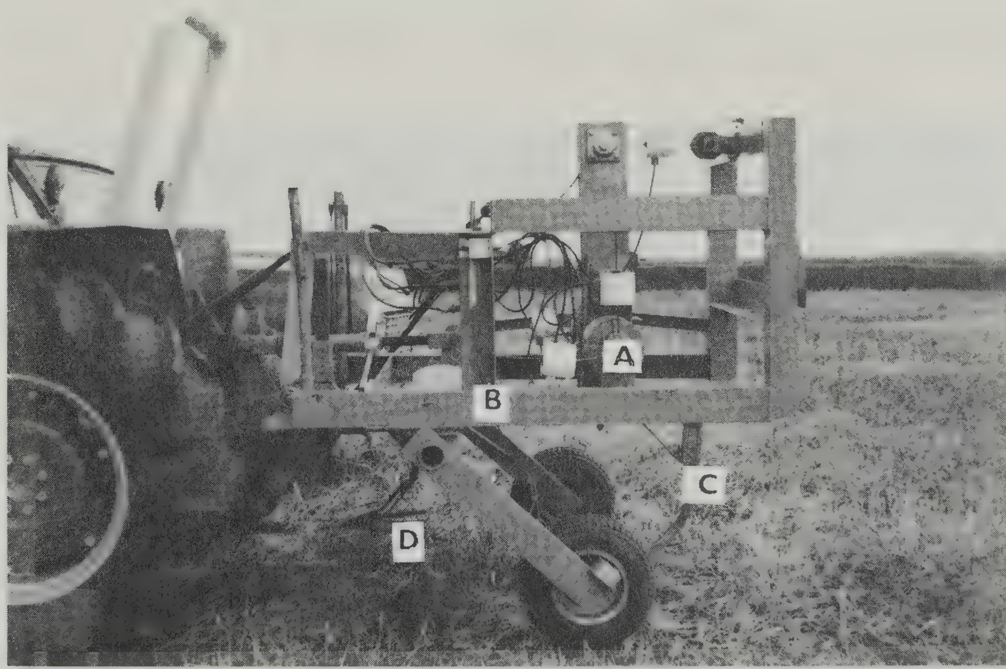

PLATE 2: MULTI-COMPONENT SENSOR.
A: ACTIVE FRAME OF THE SENSOR.
B: PASSIVE FRAME OF THE SENSOR.
C: OVERLAPPED SWEEP.
D: OVERLAPPING SWEEP.

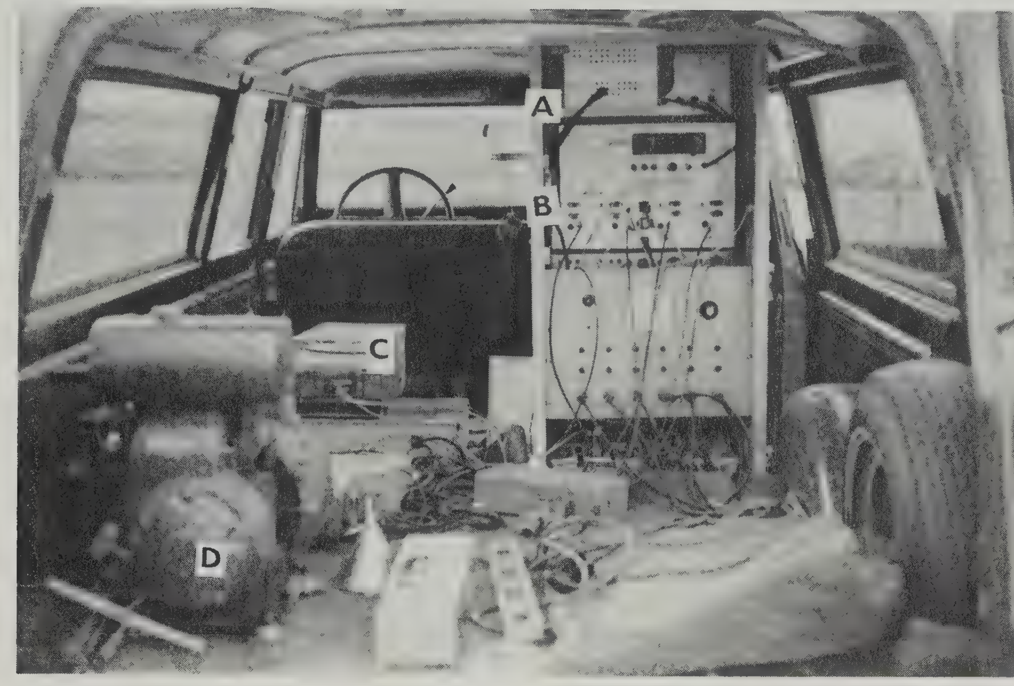

PLATE 3: DATA ACQUISITION SYSTEM.
A: ULTRA-VIOLET RECORDER.
B: ANALOG COMPUTER.
C: PAPER TAPE PUNCH.
D: GENERATOR AS A SOURCE OF POWER.

PLATE 4: GAUGE WHEEL.
A: SMALL D-C GENERATOR FOR SPEED MEASUREMENTS.

trials, was installed on the passive frame of the multi-component sensor (Plate 2). The sweep was so located as to provide the overlap of 2 inches. For the measurements of without overlap, the sweep was raised above the surface of soil.

A small d-c generator (Plate 4) was driven by one of the gauge wheels of the sensor to measure the speed of travel.

The transducers of the sensor were calibrated using 100 pound weight. By repeating the calibration an error of $\pm$ 2% was indicated.

3.5 Field Procedures.

If soil was tillable on the site for trials, soil samples were collected for the determination of moisture contents at the depths of 3 and 4 inches. The number of samples was four for each of the depths and the samples were collected from different locations within the subplot. The bulk densities were determined using the gamma ray transmission equipment referred to earlier. The depths, locations and the number of observations for the bulk densities were the same as those of moisture contents. The appropriate sweep was mounted on the sensor and the soil reacting forces and moments were recorded on a paper tape with the help of the data acquisition equipment. All the treatments of a subplot were to be completed in a single day, otherwise the whole procedure might have to be repeated because of rain the next day. In case of error, trials were to be repeated at the same site before moving the equipment to the next site.

3.6 Data Acquisition and Processing.

The data consisted of the soil reacting forces (L,S and V) and the soil reacting moments, namely, pitching, rolling and yawing. The forces have been defined by Kepner et al (15) and the moments by

Taylor (26). The centre of the active frame of the multi-component sensor, was chosen as origin for calculations of the moments. Data processing was accomplished as suggested by Harrison (12). The data on soil reacting forces was statistically analyzed, while the forces and moments were used to calculate the location of the wrench or screw axis as described by Harrison and Thivavarnvongs (13).

CHAPTER 4

RESULTS AND DISCUSSION

The values of the soil reacting forces (L, S and V) obtained from the experimental work are given in Appendices 5, 6 and 7. Analyses of variance (Appendix 3) were carried out in accordance with the model noted in section 3.2, using an MTS program (ANOVAR + SSPLIB) from the University of Alberta Computing Services Library. Table 2 (abbreviated from Appendix 3) includes main effects and the first order interactions which are at least significant for one of the soil reacting forces. The means of the soil reacting forces for each factor (main effects) are given in Tables 3 and 5. The moisture content and bulk density of the soil at the time of determining the soil reacting forces are given in Table 4.

4.1 General

The pressure applied by a tillage tool normally causes soil to fail in shear along a plane in longitudinal direction as indicated by Soehne (25). The inclination of the plane with the direction of travel (β, Figure 1) is known as angle of the failure surface (25). A decrease in this angle results in a larger failure surface and hence a larger force to cause failure.

The term "zone of influence" as used here means "the mass of soil tilled and disturbed" by the tool. The disturbed soil includes the particles which are displaced from their positions near the sides of the tool. Among the factors affecting the zone of influence

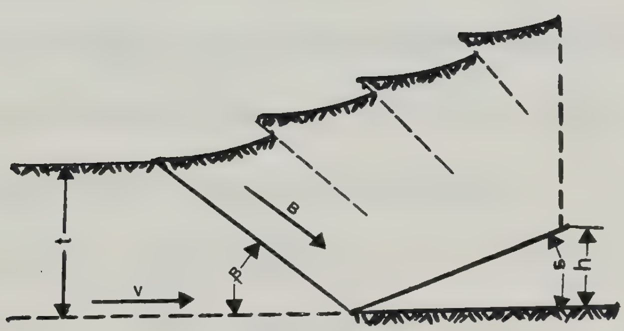

Figure 1. A section of soil moving on an inclined tool (Soehne, (25)).

are the depth of cut, width of cut and the extent of overlap. As the penetration of a tool may increase with that of speed. (Gordon (9), Wismer and Luth (29)), the depth of cut and therefore the zone of influence may also increase.

It was observed that the width of soil being tilled extended beyond the edge of the sweep when not overlapped with the extension increasing with an increase in velocity and depth; that is, the overlap, velocity and depth alter the zone of influence. It is worth noting that, an increase in the zone of influence will increase the mass of soil disturbed as well as the area of shear surface.

A moving tillage tool accelerates the soil mass in a plane parallel to the failure surface (25), and the accelerating force increases with that of speed of the tool.

According to Soehne (25)

$$B = \frac{\gamma}{g} b\ t\ v^2 \frac{\text{Sin } \delta}{\text{Sin } (\beta + \delta)}$$

Where B = accelerating force

γ = wet bulk density of soil

g = acceleration due to gravity

t = working depth

v = forward speed

δ = lift angle of the tool

β = inclination of the failure surface.

b = working width

Using the following from the present study

$\gamma = 81 \text{ lb/ft}^3$

$b = 1.33$ ft

$t = 0.3$ ft

$v = 4.4$ ft/sec

$\delta = 18.2^{\circ}$

$\beta = 34^{\circ}$ (This value was calculated from (6,18))

the components of accelerating force added to the draft and downward vertical force are only 6.5 and 4.4 pounds respectively.

4.2 Draft (L)

The main effect of soil* did not test significant for the soil reacting forces (Table 2), whereas similar variations in the clay contents of the soils (Table 4) caused significant differences in the soil reacting forces in the investigations by Gordon (9) and Taylor (26). One reason for the lack of response, in spite of large differences in the means (Table 3), can be attributed to the position of the factor in the experimental design; that is, the soils are in the main plots and as a consequence are tested with less precision than the factors in the sub-plots.

The effect of lift height is such that, the draft increases with increasing lift (Table 3). As noted in section 2.3.2, the increase in lift height results in a larger failure surface and hence a larger force to cause failure.

The draft increased with the thickness of the leading edge as well (Table 3). As indicated in section 2.3.2, the leading edge displaces some soil ahead and downwards, to achieve a passageway.

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* Soil represents the effects of texture, moisture content and bulk density.

TABLE 2: ANALYSES OF VARIANCE FOR THE SOIL REACTING FORCES.

Source of Variation	DF	L		S		V	
		MS	F	MS	F	MS	F
Replicate	2	75889	1.26	4605.8	1.20	1970.8	<1
Soil (S)	2	149610	2.48	2748.1	<1	5919.6	<1
Error (1)	4	60194		3838.9		36534	
Subtotal	8						
Make (M)	1	18005	12.28^{+++}	24.5	<1	0.34	<1
Lift (L)	1	14949	10.2^{+++}	58.9	<1	6289.8	30.48^{+++}
Thickness (T)	1	15794	10.77^{+++}	252.15	1.6	1443.8	7.24^{+++}
Depth (D)	1	1016200	693.35^{+++}	4815.8	30.62^{+++}	22420	1078.03^{+++}
Velocity (V)	1	363630	248.16^{+++}	511.32	3.25	33948	164.54^{+++}
Overlap (O)	1	564450	385.12^{+++}	99685	633.88^{+++}	26414	127.05^{+++}
OV	1	11553	7.88^{+++}	2002.9	12.74^{+++}	110.2	<1
OD	1	53565	36.54^{+++}	6889.7	43.89^{+++}	9933.4	48.14^{+++}
VD	1	35869	24.47^{+++}	318.68	2.02	2084.7	10.1^{+++}
OT	1	1822.6	1.24	743.2	4.72^{+}	112	<1
OL	1	8290.1	5.65^{+}	4.4	<1	747.57	3.62

Cont'd.

TABLE 2: Continued.

Source of Variation	DF	L		S		V	
		MS	F	MS	F	MS	F
VL	1	13348	9.1^{+++}	419.7	2.67	294.12	1.42
TL	1	3345.6	2.28	458.1	2.91	1769.6	8.58^{+++}
VM	1	6456.1	4.40^{+}	477.6	3.04	98.5	<1
TM	1	8456.3	5.77^{+++}	107	<1	6758.2	32.75^{+++}
LM	1	238.7	<1	393.5	2.5	3664.3	17.76^{+++}
OS	2	37.14	<1	490.4	3.19^{+}	221.9	1.07
DS	2	9480	6.47^{+++}	45.4	<1	2022.5	9.8^{+++}
TS	2	863.8	<1	486.9	3.1^{+}	138.5	<1
MS	2	1256.4	<1	629.6	4.0^{+}	587.74	2.84

\+ Significant at 0.05 probability level.

++ Significant at 0.01 probability level.

+++ Significant at 0.005 probability level (highly significant).

TABLE 3: MEANS OF THE SOIL REACTING FORCES.

Factors	Levels	Draft (L) (lb)	Vertical reaction (V) (lb)
Soil	Silty clay loam	176.2	-32.2
	Clay loam	231.3	-34.1
	Clay	199.6	-23.7
Make	Make 1	208.1	-30.0
	Make 2	196.9	-30.0
Lift	Low lift $1\frac{1}{64}$"	197.4	-33.3
	High lift $1\frac{1}{4}$"	207.6	-26.7
Thickness	Thin $\frac{1}{4}$"	197.3	-31.6
	Thick $\frac{5}{16}$"	207.7	-28.4
Depth	Depth 3"	160.5	-10.3
	Depth 4"	244.5	-49.6
Velocity	Velocity 3 mph	177.4	-22.3
	Velocity 6 mph	227.6	-37.6
Overlap	Without overlap	233.8	-36.7
	With overlap	171.2	-23.2

TABLE 4: SOIL CONDITIONS.

(a) Soil Texture.

Soil	% Clay	% Sand	% Silt	Soil
Soil 1	28	26	46	*Silty clay loam to clay loam
Soil 2	30	31	39	Clay loam
Soil 3	55	17	28	Clay

(b) Moisture Contents.

Soil	Rep-li-cate	Moisture contents on dry basis (%) at		Moisture contents on wet basis (%) at	
		3"	4"	3"	4"
Silty clay loam	1	38.3	40.4	27.6	28.4
	2	37.5	38.5	27.2	27.8
	3	33.5	33.9	25.0	25.3
Clay loam	1	22.4	23.4	18.3	19.0
	2	29.5	30.2	22.8	23.1
	3	29.6	29.6	22.6	22.6
Clay	1	29.4	32.1	22.7	24.2
	2	30.5	31.4	23.3	23.8
	3	22.2	20.1	18.0	16.6

Cont'd.

* Will be referred to as silty clay loam.

TABLE 4: Continued

(c) Bulk Densities (lb/ft^3)

Soil	Replicate	Wet bulk density at 3"	Wet bulk density at 4"	Dry bulk density at 3"	Dry bulk density at 4"
	1	72.3	72.3	52.3	51.4
Silty clay loam	2	64.2	71.7	45.4	51.8
	3	78.6	83.6	58.9	62.4
	Means	71.7	75.8	52.2	55.2
	1	98.5	94.2	80.5	76.3
Clay loam	2	84.8	81.1	65.5	62.3
	3	68.0	65.5	52.5	50.5
	Means	83.6	80.3	66.2	63.0
	1	79.8	84.8	61.6	64.2
Clay	2	80.4	92.9	61.6	70.7
	3	79.8	106.0	65.3	88.2
	Means	80.0	94.6	62.8	74.4

The amount of displacement increases with an increase in the thickness of the leading edge thereby increasing both the draft and the vertical reaction. The reason for the draft for one make of sweeps to be greater than the other cannot be clearly stated. The width of cut, lift and edge thickness of the sweep with greater draft, are larger but there are also small differences in the length and approach angle which may also affect the draft.

The draft increased with that of depth and the increase is associated with the increase in the area of shear surface with the depth of cut.

The draft increased by 50 pounds for an increase of 3 mph in speed (Table 3). As noted in section 4.1, the horizontal component of the accelerating force is only 6.5 pounds for a change in speed of 3 mph; that is, the accelerating force accounts for only about 15% of the increase in the draft and, therefore, the increase is mainly due to changes in the strength properties of the soil as advocated by Hendrick and Gill (14), Payne (19) and, Rowe and Barnes (21). However, a part of the increase in draft with that of speed may be associated with the increase in the zone of influence; that is, the increase in speed increases penetration as well as the width of soil tilled.

Overlap decreases the draft because the sweep encounters a tilled portion of the soil which has less strength.

The zone of influence, noted previously, is affected by the overlap, depth of cut and velocity of the tool. Therefore, the differential response of overlap and velocity (Figure 2) may be

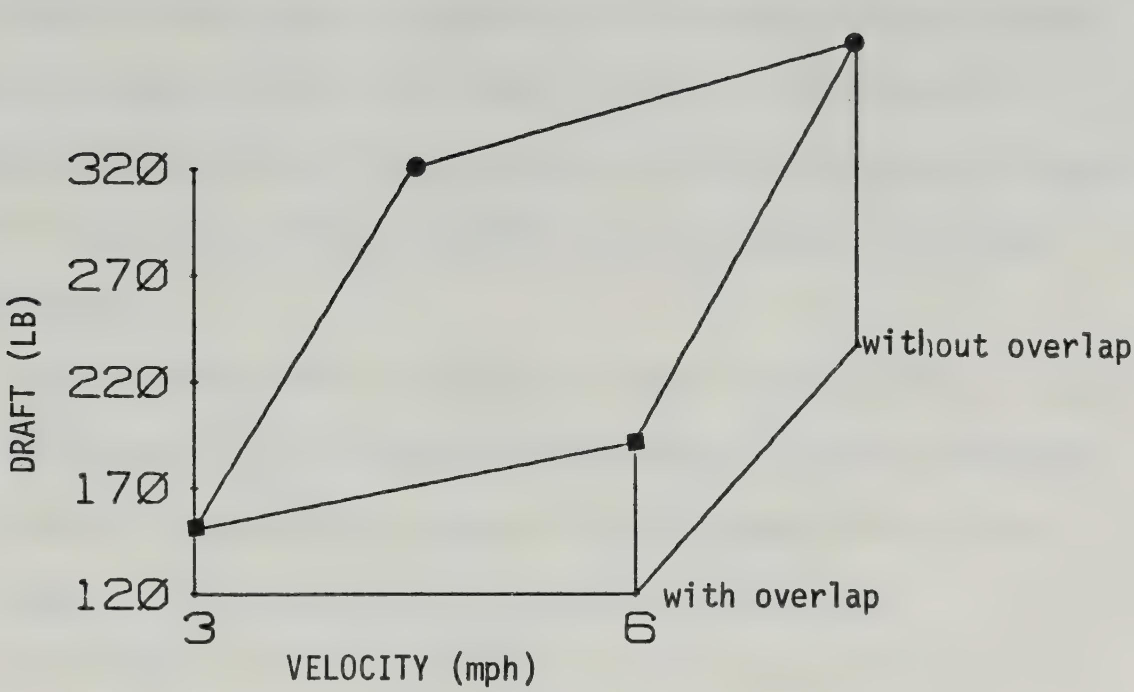

Figure 2. The velocity-overlap interaction for draft.

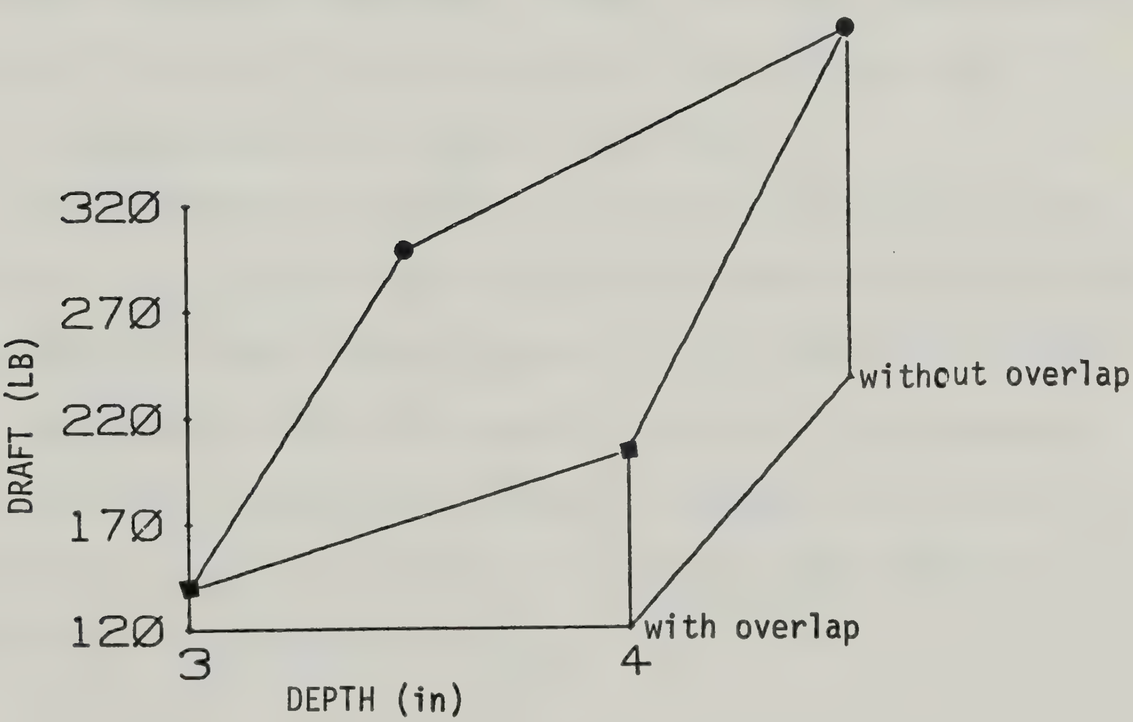

Figure 3. The depth-overlap interaction for draft.

attributed to the change in the zone of influence with and without overlap and the two levels of velocity. In a similar way the differential responses of depth-overlap and depth-velocity (Figures 3, 4) are also associated with differential changes in the zone of influence.

Figure 5 indicates that there is little or no increase in draft with an increase in lift height for the sweeps that are overlapped, but there is a substantial increase for the sweeps that are not overlapped. The reason for this response is not clear.

The effect of lift height on the draft is restricted to the higher speed (Figure 6). Though Gill and Vanden Berg (8) indicate that the angle of the failure surface with the horizontal is sensitive at the higher tool velocity. They did not indicate whether the angle increases or decreases. Perhaps, the angle decreases at a higher tool velocity increasing the draft, and that the angle is further decreased with an increase in the lift.

The differential responses of make-velocity and make-thickness (Figures 7, 8), are small and like the main effect due to make noted previously, the reason for the respones are not clear. On the other hand, the change in draft for clay soil is greater for a change in depth than the other two soils (Figure 9) because the difference in the bulk density of the clay soil over the two depths (Table 4), are greater than for the other two soils.

4.3 Vertical Reaction (V)

The vertical reacting force was downward (negative) for all the

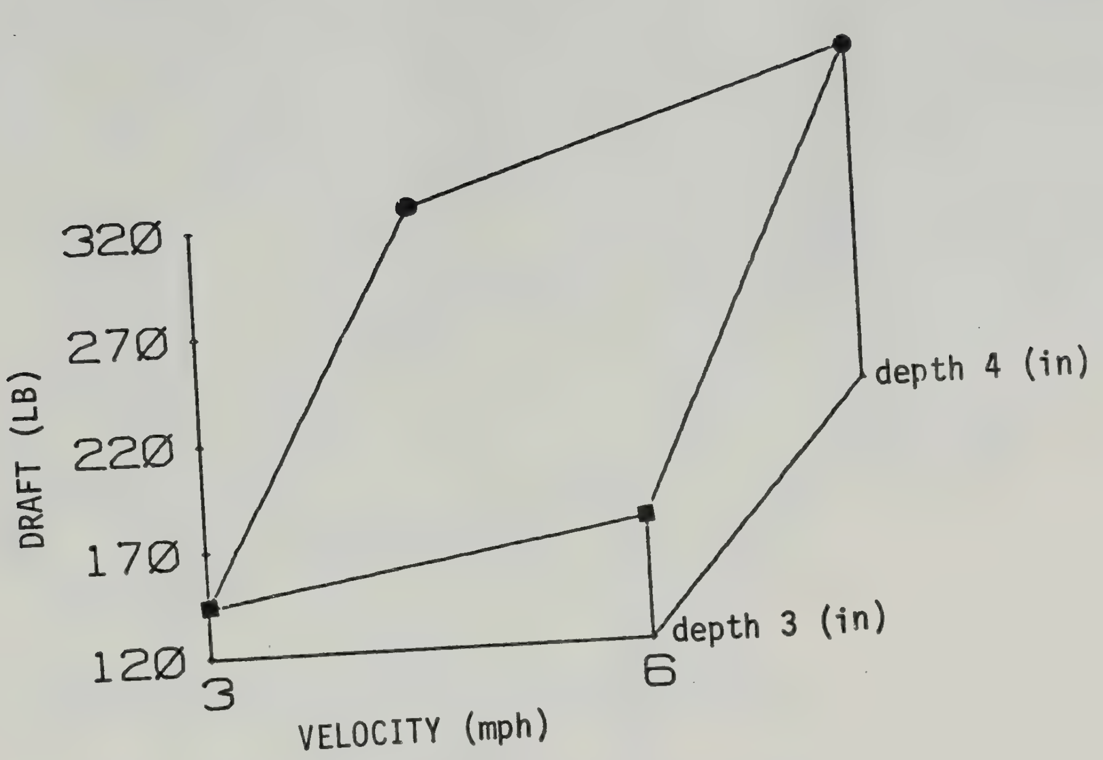

Figure 4. The velocity-depth interaction for draft.

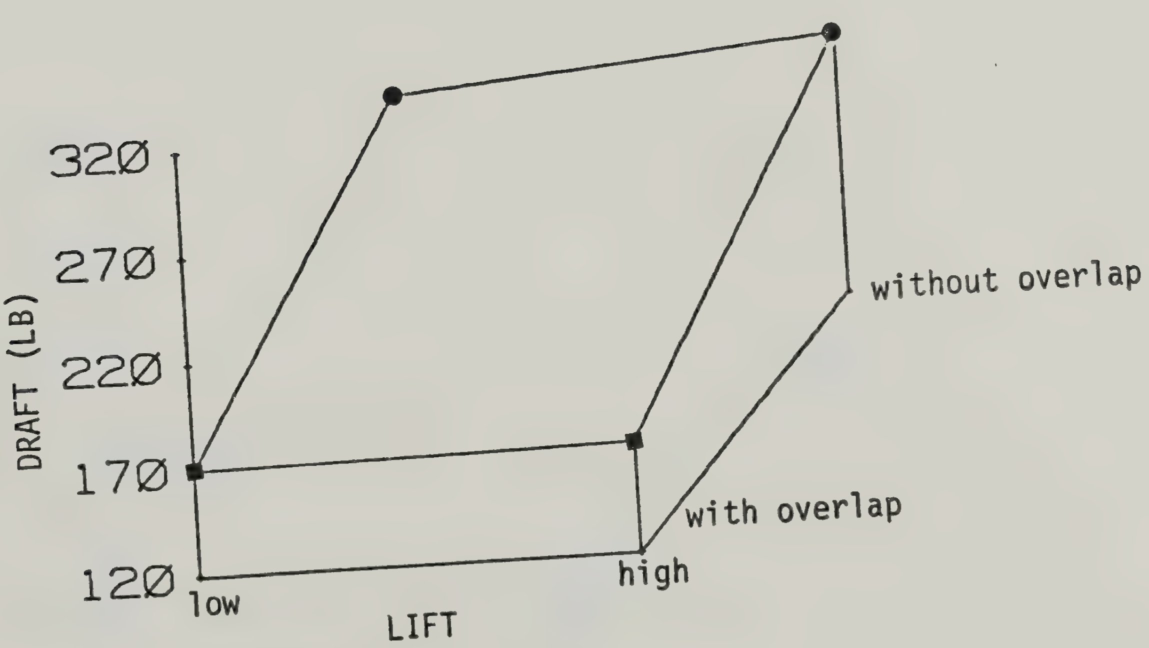

Figure 5. The lift-overlap interaction for draft.

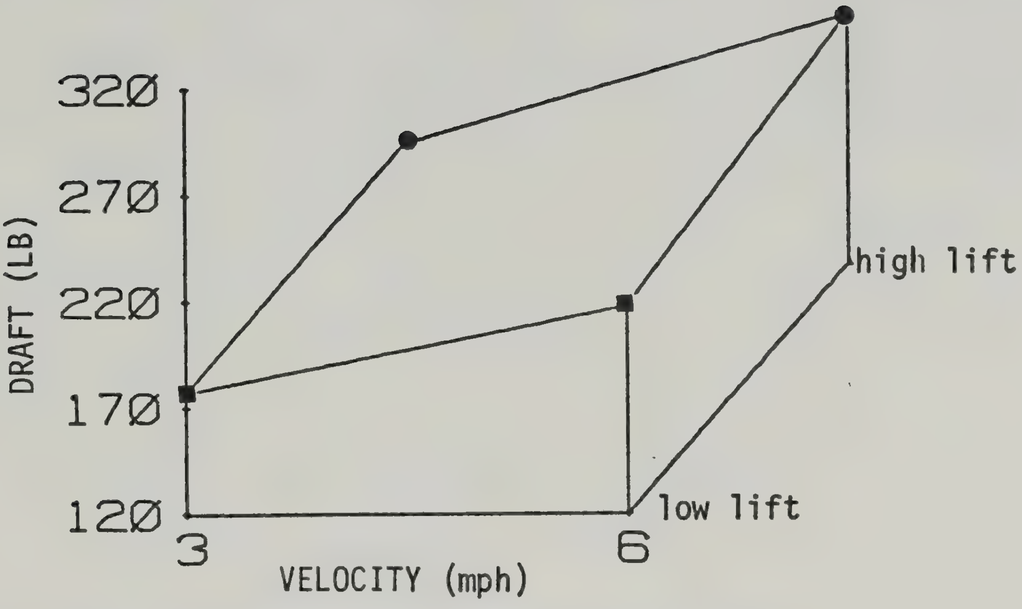

Figure 6. The velocity-lfit interaction for draft.

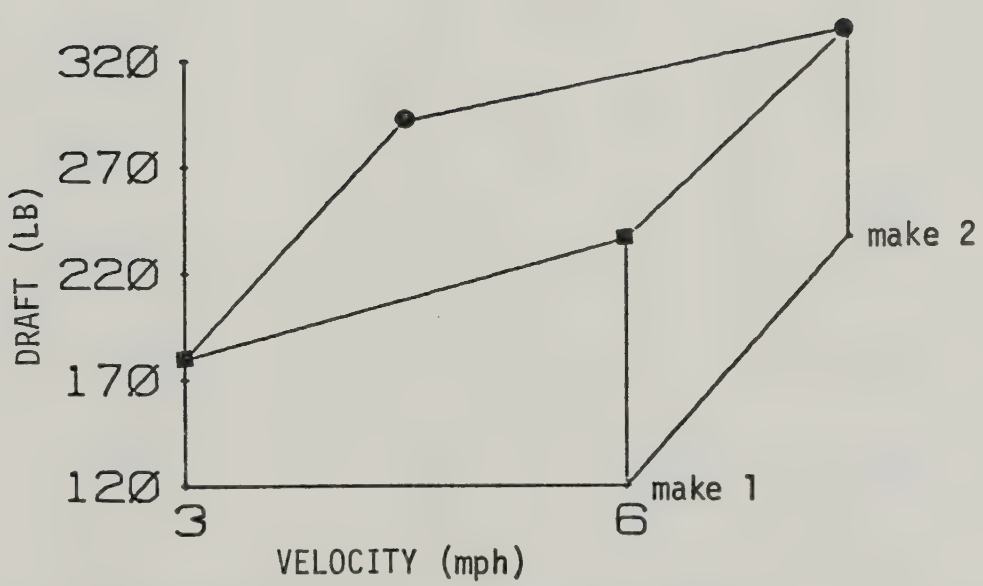

Figure 7. The velocity-make interaction for draft.

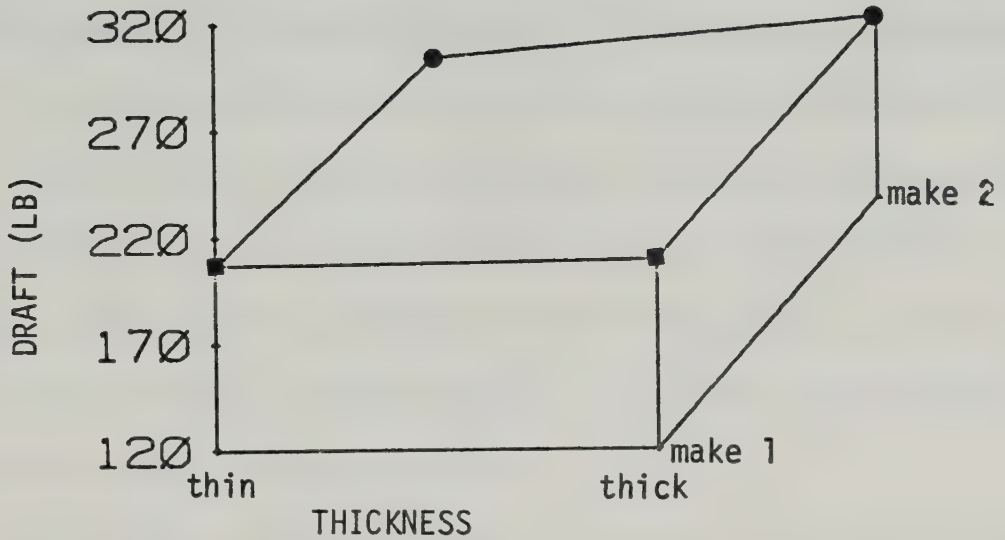

Figure 8. The thickness-make interaction for draft.

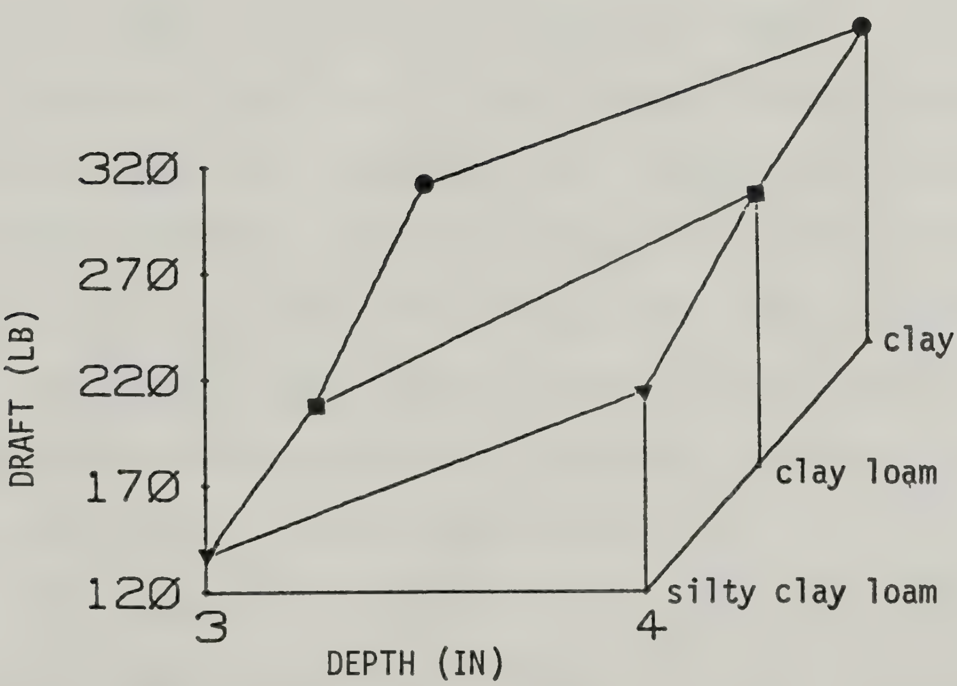

Figure 9. The depth-soil interaction for draft.

levels of all the factors in the study because the force was affected primarily by the amount of soil in contact with the surface of the sweep. Increasing the depth of cut increased the weight of soil decreasing the vertical reaction substantially (Table 3).

The vertical reaction increased as the lift increased (Table 3). As noted previously with draft, the angle of shear surface decreases with a corresponding increase in the lift height and this may reduce the weight of soil on the surface of the sweep and therefore increasing the vertical reaction.

To a lesser extent the vertical reaction increased with an increase of thickness (Table 3). As discussed under draft, the change is attributed to the displacement and compaction of the soil, under the leading edge of the sweep, which is greater for the thicker sweep, which in turn, partially offsets the weight of the soil in contact with the top surface of the sweep.

As noted in section 4.1, the increase in the accelerating force, from 3 to 6 mph is 4.4 pounds, which is added to the weight of soil in contact with the top surface of sweep thereby decreasing the vertical reacting force. This accounts for about 30 percent of the decrease (Table 3), the remaining part of the decrease may be attributed to the effect of the shank because its lift angle differs from the sweep and soil piles up ahead of it.

With regard to the effect of overlap, the vertical reaction increases when the sweep is overlapped (Table 3). It may be that the overlapping sweep was slightly below the overlapped sweep reducing the amount of compaction and therefore increasing the

vertical reaction.

The differential response of overlap and depth of cut (Figure 10) is attributed to the zone of influence which extends beyond the width of sweep increasing with depth but to a lesser extent for a sweep which is overlapped. It is not clear why there is a differential response of velocity and depth of cut (Figure 11). The interaction is small and therefore is of little interest.

Figure 12 indicates that, for the lower lift there is little or no response in the vertical reaction over the two thicknesses but for the higher lift this is not the case. The reason for this differential response is not clear but it indicates that the effect of thickness is eliminated if a lower lift sweep is used.

Figures 13 and 14 indicate that the vertical reaction is independent of the thickness and lift for make 2, but the vertical reaction increases for the increases in the thickness and lift of make 1. Again it is not clear why these differential responses occurred. Similarly the reason for the differential response of soil and depth of cut (Figure 15) is not apparent.

4.4 Lateral Reaction (S)

For trihedral wedge type tillage tools the soil usually fails first in the direction of travel (primary failure planes) then perpendicular to the direction of travel (secondary failure planes). The lateral reacting force is the result of stressing the soil perpendicular to the direction of travel.

A sweep is a symmetrical tool and therefore a lateral reacting

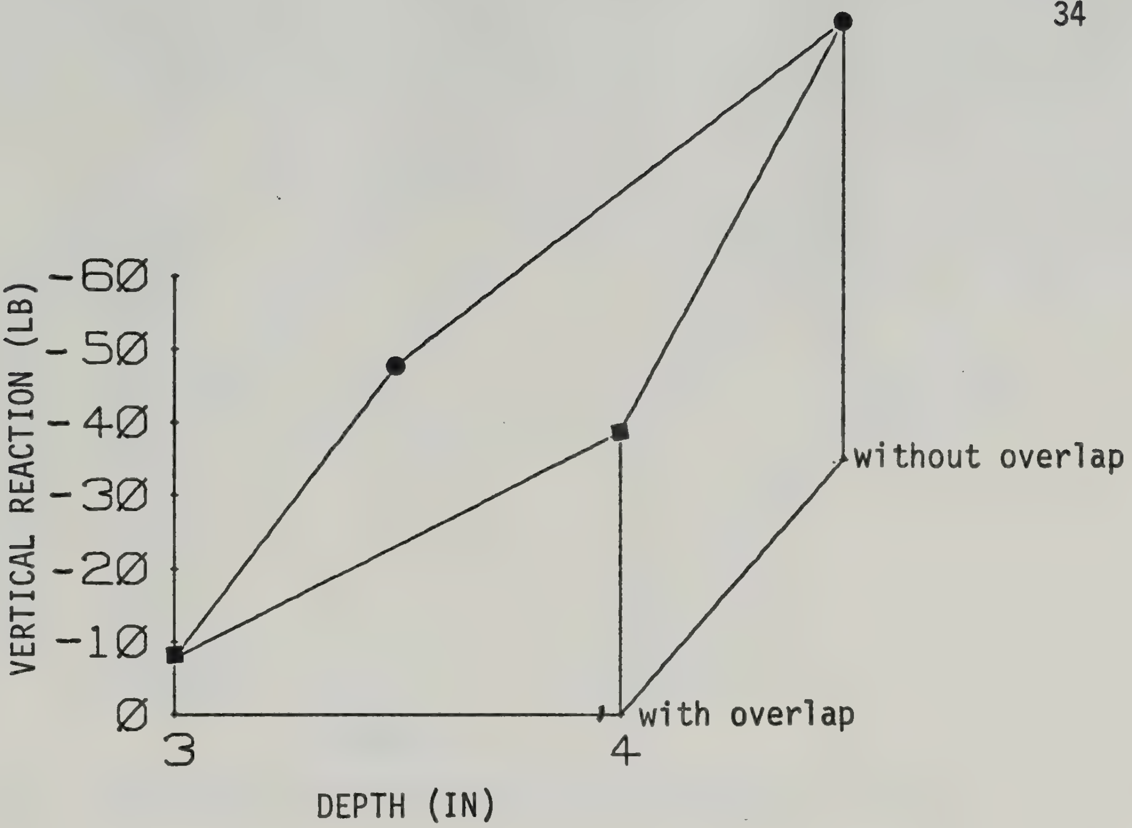

Figure 10. The depth-overlap interaction for vertical reaction.

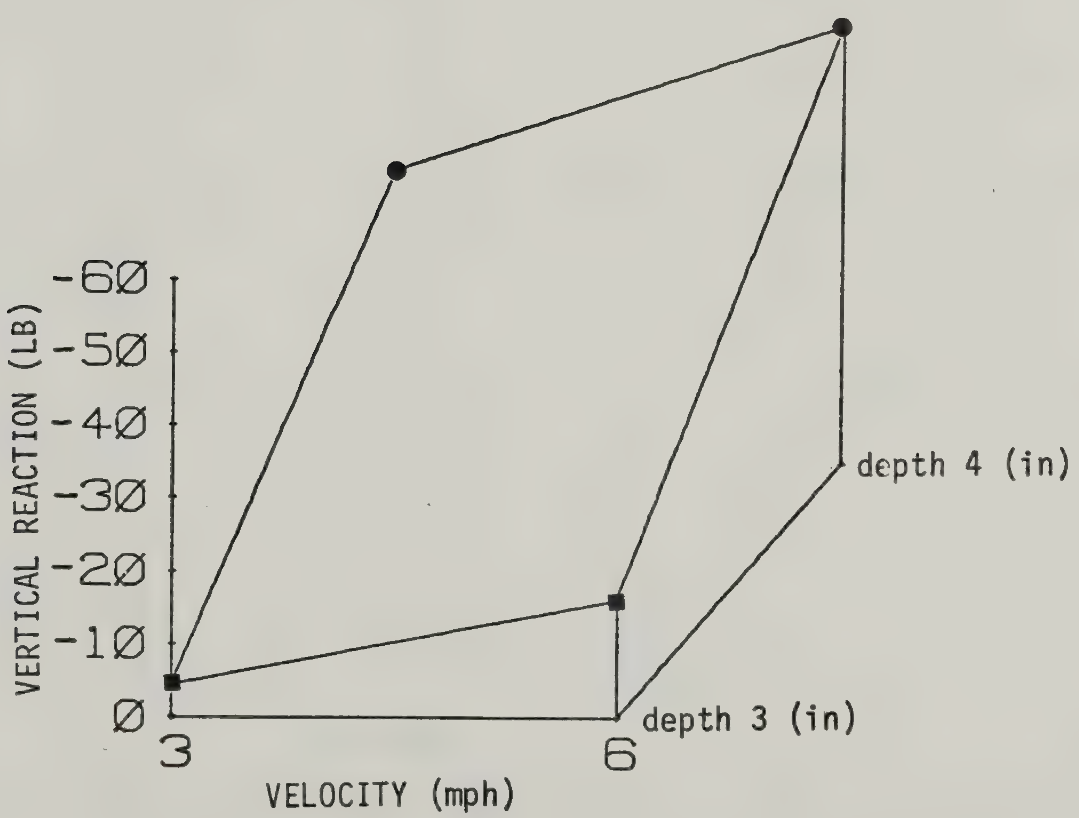

Figure 11. The velocity-depth interaction for vertical reaction.

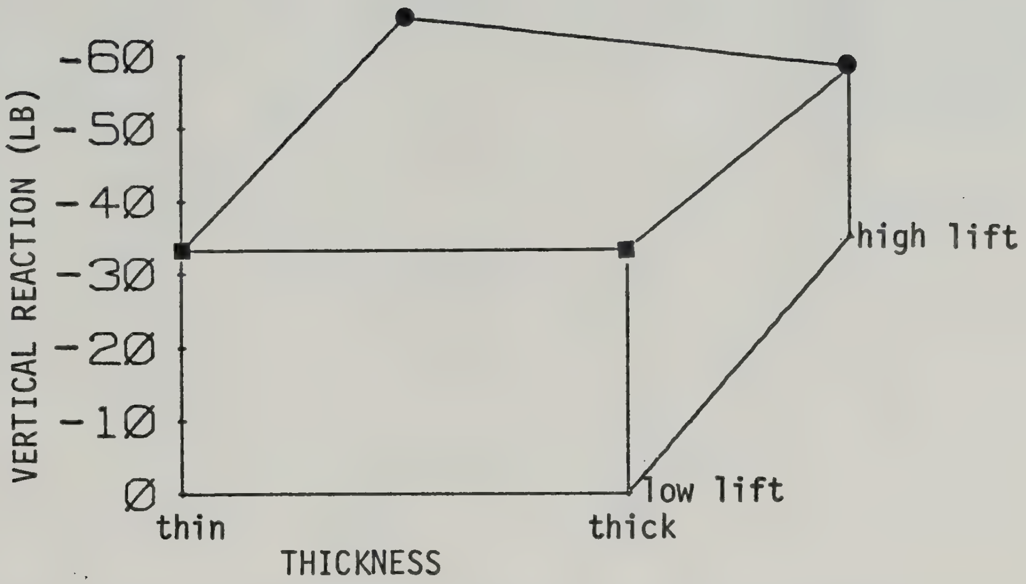

Figure 12. The thickness-lift interaction for vertical reaction.

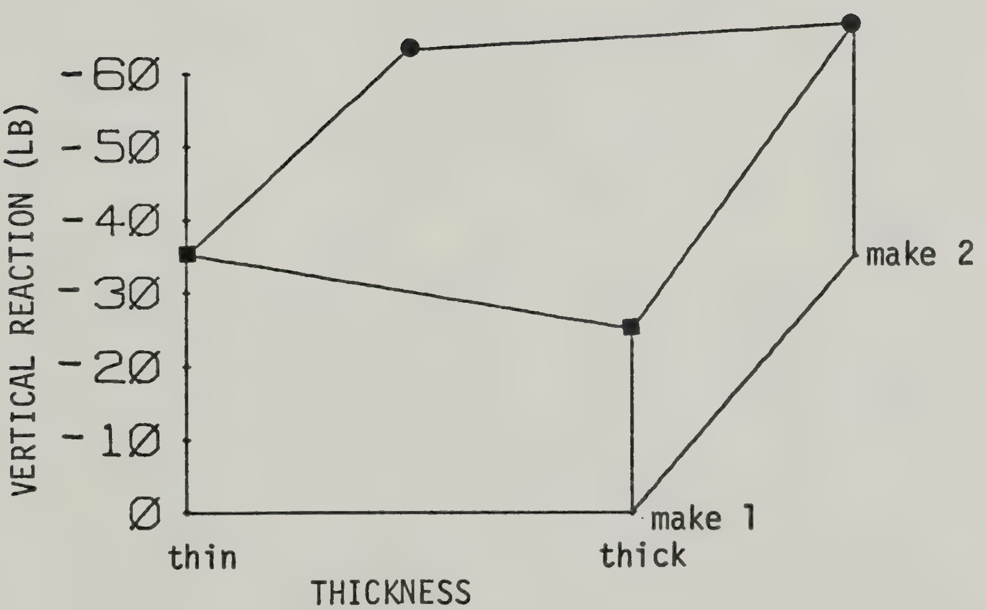

Figure 13. The thickness-make interaction for vertical reaction.

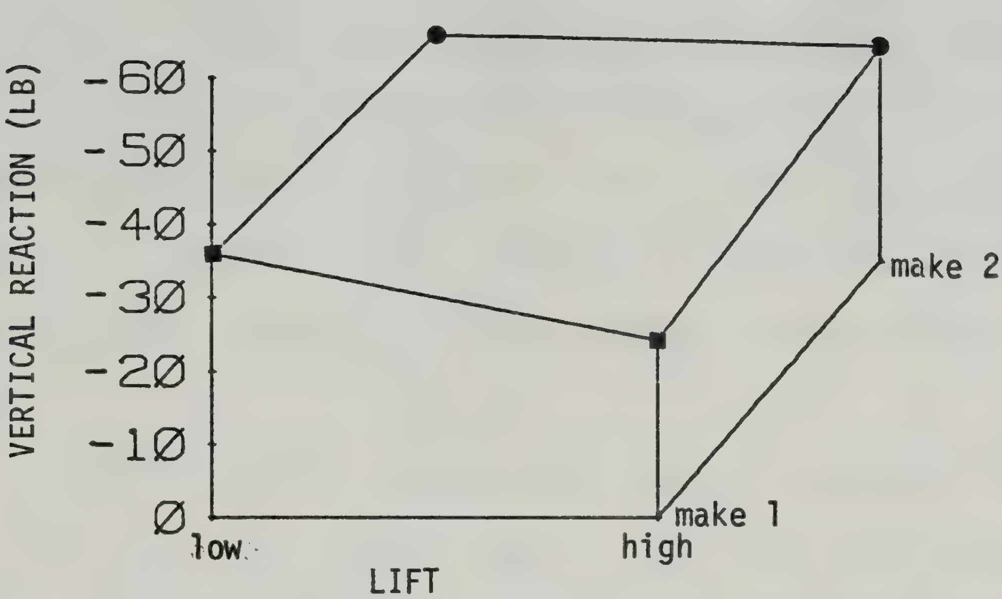

Figure 14. The lift-make interaction for vertical reaction.

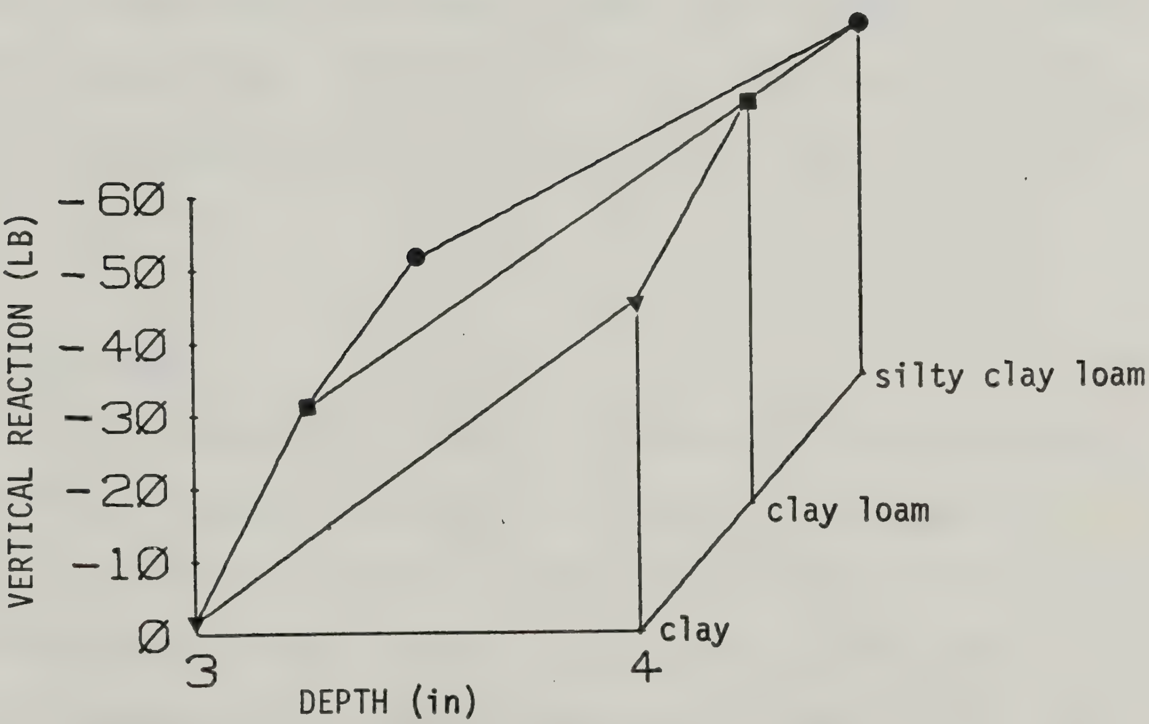

Figure 15. The depth-soil interaction for vertical reaction.

force to the right is equal and opposite to a lateral reacting force to the left. However, an overlapped sweep encounters a block of soil asymmetrical in strength and as a consequence there is a net lateral reacting force acting to the left or right depending on the location of the weakened soil. Like the draft the net lateral reacting force or simply the lateral reacting force increases with depth.

Some of the effects tested significant for the lateral reacting force (Table 2). The effects might be significant only because of overlap. In order to test the effects, a separate analysis of variance was conducted for the overlapped sweeps. The analysis indicated that depth and speed tested significant (Table 5). No doubt the reasons for the changes in the lateral force are the same as those advanced for the changes in the draft for these two factors namely increased shear area with depth and an increase in the soil strength with speed and the increase in the zone of influence.

4.5 Screw Axes

The data obtained to calculate the moments of pitching, yawing and rolling are given in Appendices 8, 9 and 10. Using vector mechanics the three moment vectors are combined with the three force vectors to determine the location of the wrench or screw axis, a method to represent the system of forces on tillage tool (8). As noted previously, the procedure used for the location of screw axis

TABLE 5: MEANS OF LATERAL REACTIONS WITH OVERLAP.

Factor	Levels	Lateral reaction (lb)
Soil	Silty Clay Loam	23.9
	Clay Loam	28.4
	Clay	32.6
Make	Make 1	28.2
	Make 2	28.3
Lift	Low Lift 1 1/64"	27.9
	High Lift 1 1/4"	28.1
Thickness	Thin 1/4"	27.8
	Thick 5/16"	28.7
Depth*	Depth 3"	21.9
	Depth 4"	34.6
Velocity*	Velocity 3 mph	25.5
	Velocity 6 mph	31.0

* tested significant (Appendix 4).

is the same as detailed by Harrison and Thivavarvongs (13). Screw axes were drawn for all the main effects and the first order interactions but only those are presented having differences with some practical significance.

Except for Figure 19, the locations and directions of the screw axes in the yawing planes are similar for each level of different factors. The similarity is associated with the negligible lateral reaction due to the symmetrical nature of the sweep. In Figure 19, the direction and location of screw for the overlapped sweep is affected because there is a lateral reaction.

In the pitching plane, there is a little difference in the locations of the screw for each level of the factors of lift, thickness, velocity and overlap (Figures 16, 17, 18 and 19). The directions of the screw are associated with the directions and magnitudes of the draft and vertical reacting force (Table 3). The screw axis passes near the tip of the sweep in the pitching plane indicating that the highest pressure occurs near the tip as can be noted by the rapid wear in this area. In Figure 20, the screw axis does not intercept the sweep in the pitching plane. As there is no apparent mechanism for this to occur, it may be assumed to be a small error rather than of an actual effect.

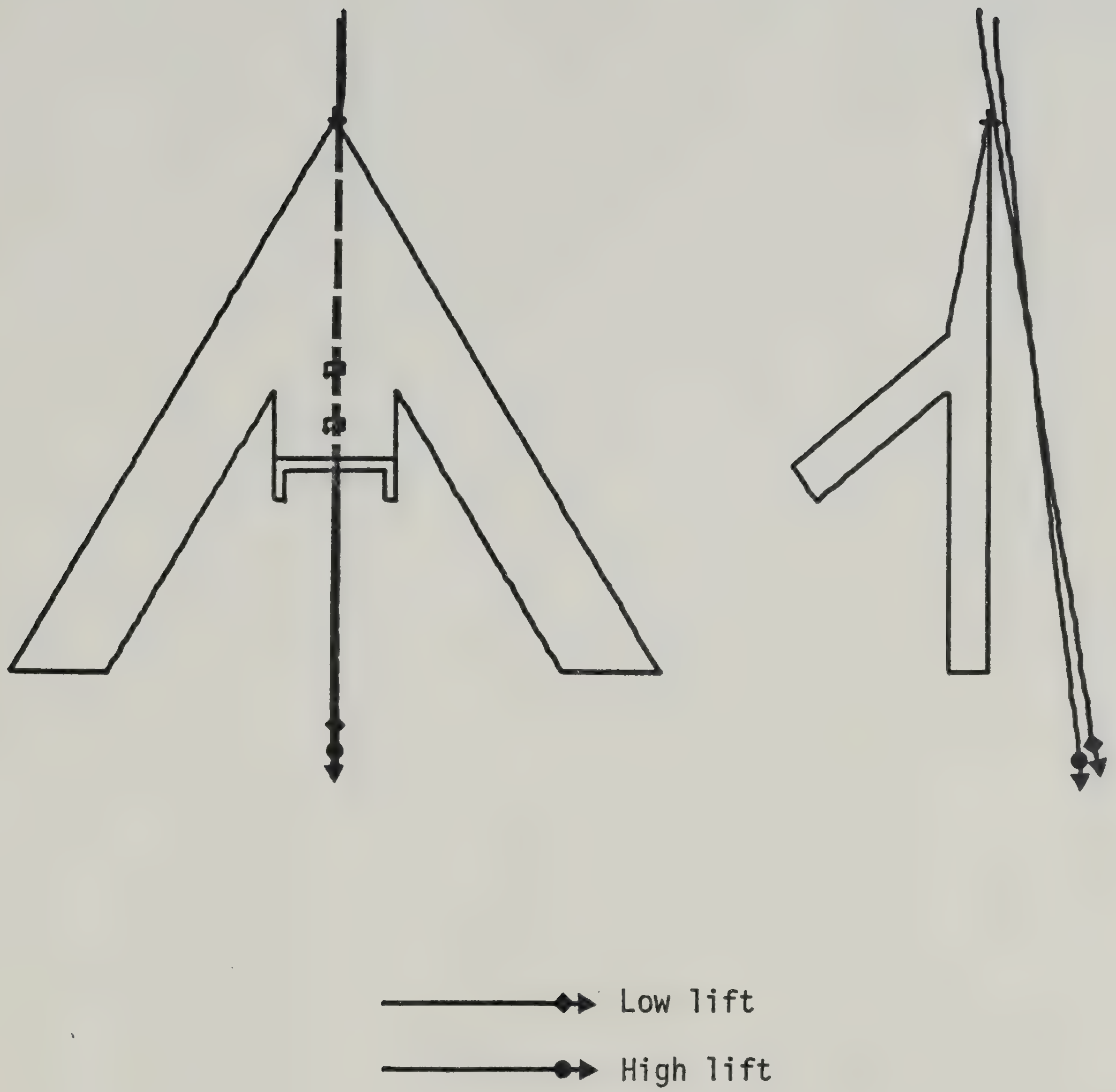

Figure 16. Locations of screw axes for the two levels of lift without overlap.

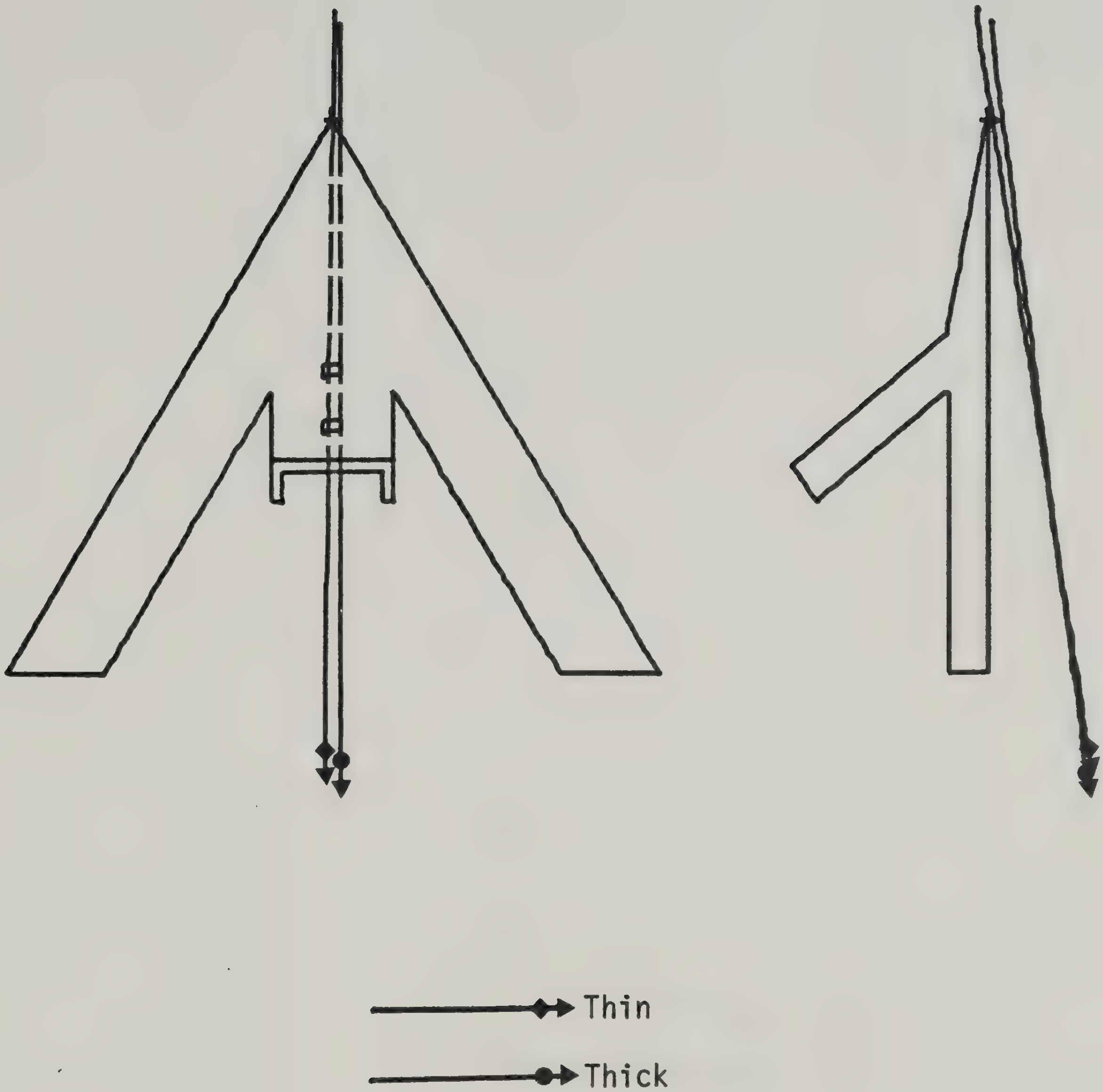

Figure 17. Locations of screw axes for the two levels of thickness without overlap.

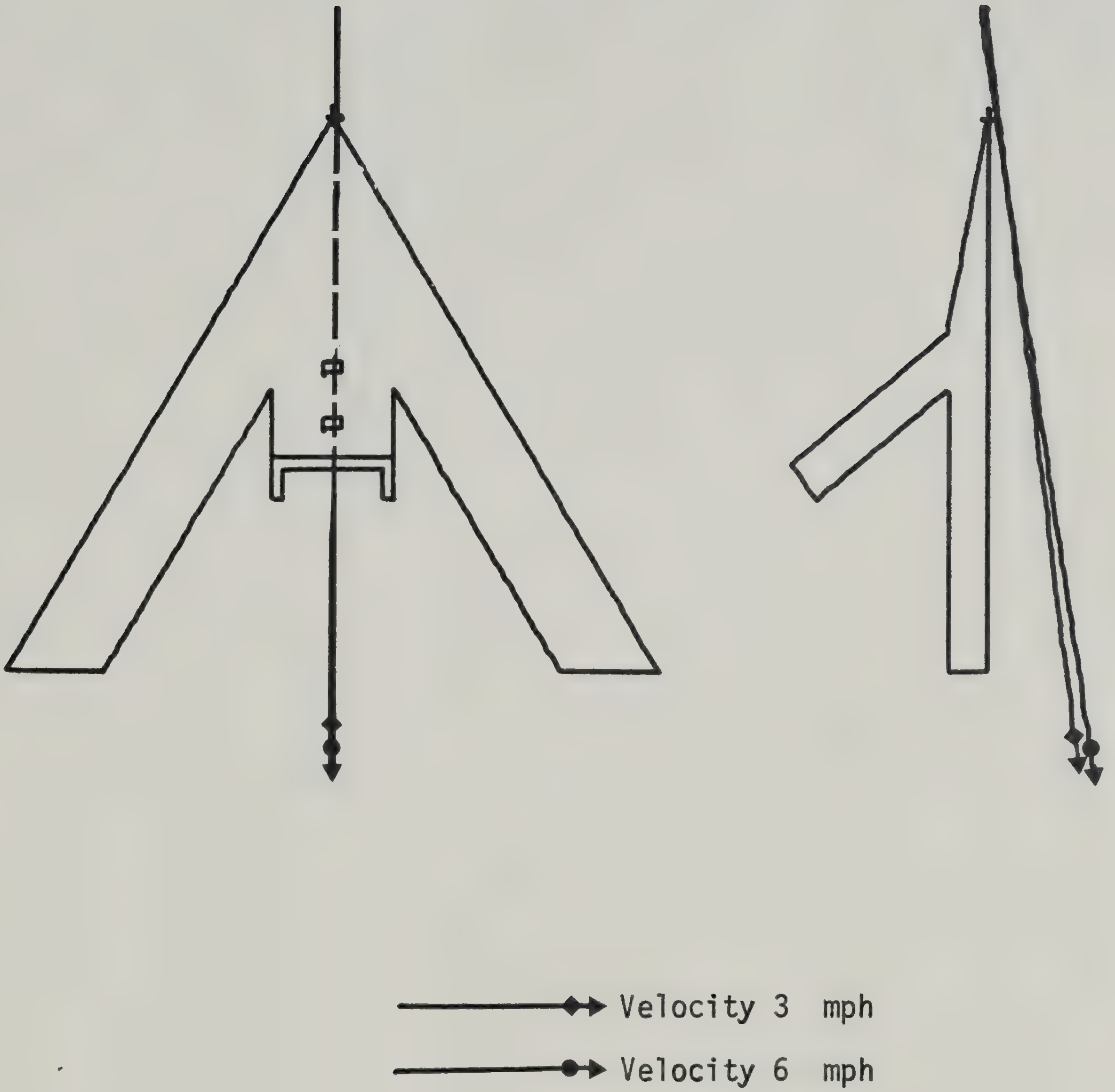

Figure 18. Locations of screw axes for the two levels of velocity without overlap.

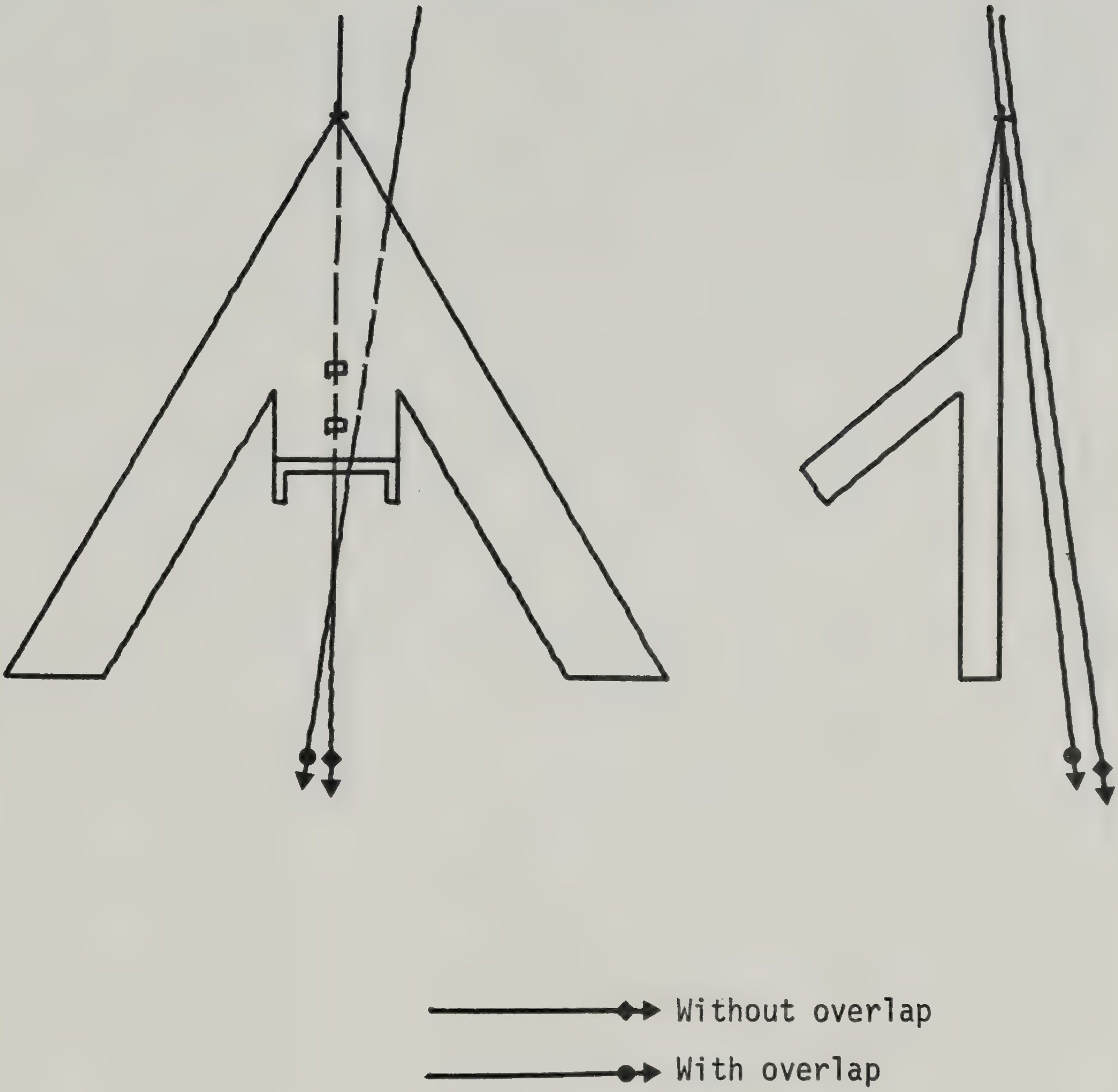

Figure 19. Locations of screw axes for the two levels of overlap.

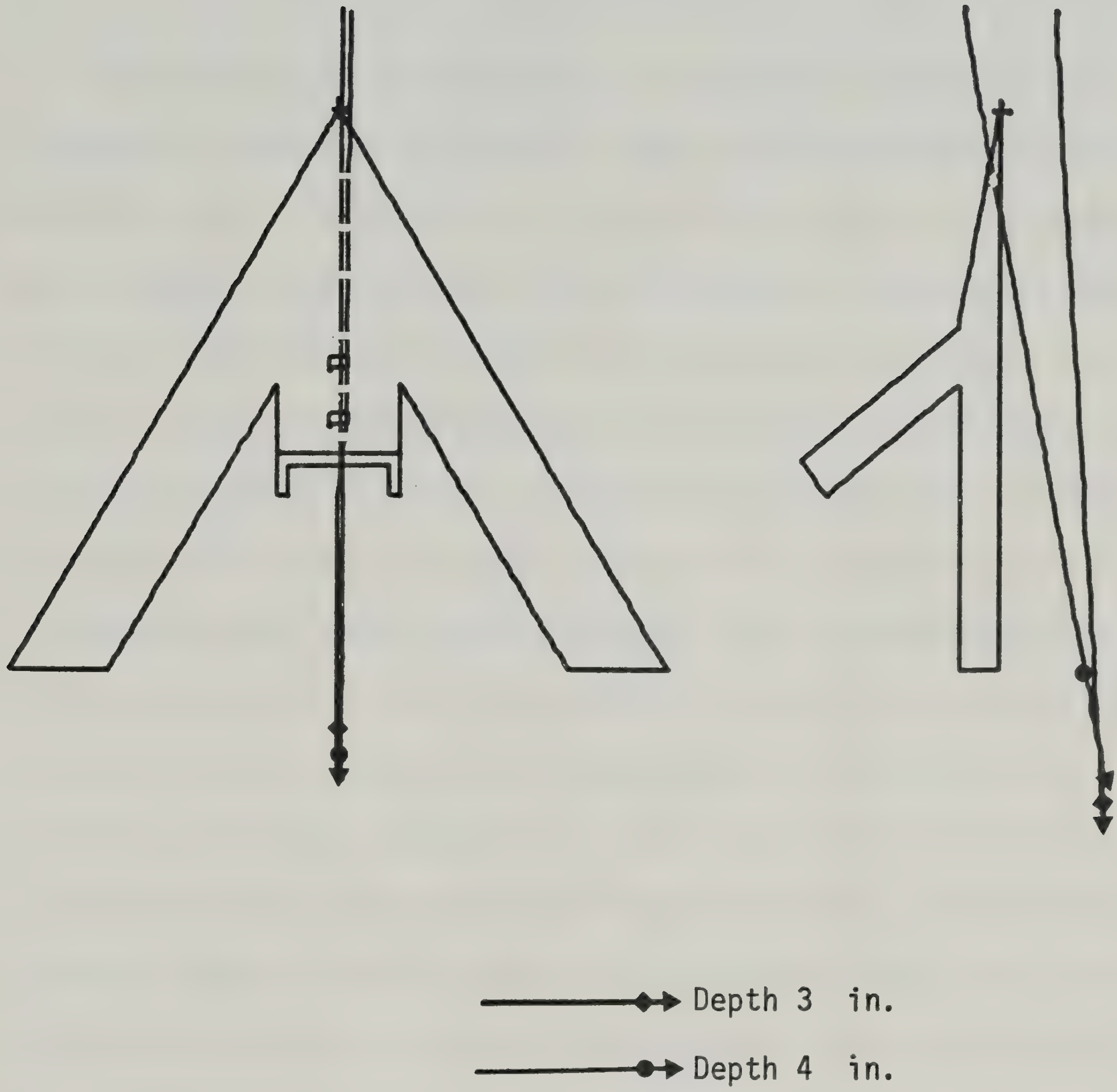

Figure 20. Locations of screw axes for the two levels of depth without overlap.

CHAPTER 5

SUMMARY AND CONCLUSIONS

The results of the experiment are primarily associated with the zone of influence and angle of shear or failure surface with the horizontal. As regards the zone of influence, it is affected by the depth of cut, whether or not the sweep is overlapped, speed of travel and their interactions with one another, whereas, the angle of shear surface decreases with an increase in lift height and that the decrease is further enhanced at the higher tool velocity. Both the draft and the vertical reacting force increase as the thickness of the leading edge increases. This has been attributed to the compaction by the leading edge. Similarly it is noted that the force accelerating the soil mass because of increased tool velocity, partially, accounts for the changes both in the draft and vertical reacting force with the change in velocity. The lateral reacting force is affected only by the speed and depth, and that the effect is restricted to the overlapped sweeps. On the other hand there were a few responses, such as make, soil and some interactions that could not be accounted for. In particular the reason for the screw axis not intercepting the sweep in the pitching plane is unknown.

With regard to the design and operation of the sweeps, the results indicate that the high lift sweep requires 5% more draft than that of the low lift. Because there appears to be no benefit as to the final soil condition and because the high lift sweep does

not penetrate well, its use is questionable. The thick edge sweep, like that of the high lift, requires 5% more draft as compared to the thin edge sweep and the thick edge sweep also results in a poorer penetration. Unless the thick edge sweep is required to minimize stone damage, its use in stone free land is also questionable. The depth of tillage is a cultural practice but again the advantages of deep tillage should be weighed against the increase in draft which can exceed 50% for increased depth of 3 to 4 inches.

The draft increased more than 25% for an increase in speed from 3 to 6 mph. The operation of a tillage implement at a higher speed is advantageous in the way that it reduces tire size and the ballast of the tractor but this must be compared to the energy requirements at the higher speed. The decrease in the vertical reaction with that of speed indicates that penetration can be improved by increasing the speed.

The magnitude and direction of the lateral reacting force becomes important for the design of asymmetrical cultivators in which skewing is often a problem. The mean value of the lateral reacting force for an overlapped sweep was more than 25 pounds which should be further adjusted according to the speed of travel and depth of cut.

The screw axes pass near the tip of the sweep indicating area of maximum pressure and therefore confirming the present practice of keeping the tip harder.

As regards further experimental work, some of the results discussed in the prior sections do not have well established

mechanisms which will account for the responses obtained. For example, the effect of make on draft and the effect of lift height or speed on vertical reacting force. Another example is screw axis not intercepting the sweep. A laboratory study in which the angle of failure surface and zone of influence can be observed might help in developing the mechanisms causing the responses obtained.

CHAPTER 6

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APPENDIX 1: DIMENSIONS OF SWEEPS USED.

Sweep Feature			Dimensions					
Make	Lift	Thickness	Width (ins.)	Length (ins.)	Approach angle (deg.)	Attachment angle (deg.)	Edge Thickness (ins.)	Lift (ins.)
Make 1	Low	Thin	16	14 1/2	67	57	.254	1 1/8
		Thick	16 1/4	14 1/4	69	57	.310	1 1/16
	High	Thin	16	13 3/4	71	50	.258	1 1/4
		Thick	16 1/4	14	71	50	.302	1 5/16
Make 2	Low	Thin	15 3/4	15 1/2	61	57	.256	14/16
		Thick	15 3/4	15 1/2	61	53	.304	1
	High	Thin	16 1/8	14 1/4	69	50	.252	1 1/16
		Thick	16 1/4	14 1/2	68	54	.304	1 1/4
Make 1 (averages)			16 1/8	14 1/8	69	54	.281	1 3/16
Make 2 (averages)			16	15	65	54	.279	1 1/16

APPENDIX 2: EXPERIMENTAL ORDER

Replicate 1		
Soil 1	Soil 2	Soil 3
*	*	*

Replicate 2		
Soil 1	Soil 2	Soil 3
*	*	*

Replicate 3		
Soil 1	Soil 2	Soil 3
*	*	*

* Excepting Soils the factors in Table 1 were randomized.

APPENDIX 3: ANALYSES OF VARIANCE FOR SOIL REACTING FORCES

Source of Variation	DF	L		S		V	
		MS	F	MS	F	MS	F
Replicate (R)		75889	1.26	4605.8	1.20	19708	<1
Soil (S)	2	149610	2.48	2748.1	<1	5919.6	<1
Error (1)	4	60194		3838.9		36534	
Subtotal	8						
Make (M)	1	18005	12.28+++	24.5	<1	0.34	<1
Lift (L)	1	14949	10.20+++	58.9	<1	6289.8	30.48+++
Thickness (T)	1	15794	10.77+++	252.15	1.60	1493.8	7.24++
Depth (D)	1	1016200	693.35+++	4815.8	30.62+++	222420	1078.03+++
Velocity (V)	1	363630	248.16+++	511.32	3.25	33948	164.54+++
Overlap (O)	1	564450	385.12+++	99685	633.88+++	26214	127.05+++
OV	1	11553	7.88+++	2002.9	12.74+++	110.2	<1
OD	1	53565	36.54+++	6889.7	43.81+++	9938.4	48.14+++
VD	1	35869	24.47+++	318.18	2.02	2084.7	10.10+++
OT	1	1822.6	1.24	743.2	4.72+	112	<1
VT	1	1106.1	<1	11.4	<1	18.9	<1
DT	1	2190.6	1.49	111.4	<1	419.2	2.03

APPENDIX 3: Continued

Source of Variation	DF	L		S		V	
		MS	F	MS	F	MS	F
OL	1	8290.1	5.65+	4.4	<1	747.57	3.62
VL	1	13348	9.10+++	419.7	2.67	294.12	1.42
DL	1	126	<1	17.2	<1	91.5	<1
TL	1	3345.6	2.28	458.1	2.91	1769.6	8.58+++
OM	1	571.21	<1	9.20	<1	7.9	<1
VM	1	6456.1	4.40+	477.6	3.04	98,5	<1
DM	1	5013.8	3.42	54.9	23.6	23.6	<1
TM	1	8456.3	5.77+	107	<1	6758.2	32.75+++
LM	1	238.7	<1	393.5	2.50	3664.3	17.76+++
OS	2	37.14	<1	490.4	3.19+	221.9	1.07
VS	2	1298.9	<1	376.3	2.39	596.5	2.89
DS	2	9480	6.47+++	45.4	<1	2022.5	9.80+++
TS	2	863.8	<1	486.9	3.10+	138.5	<1
LS	2	640.7	<1	113.7	<1	117.4	<1
MS	2	1256.4	<1	629.6	4.0+	587.74	2.84
OVD	1	7291.7	4.97+	550.5	3.5	424	2.05
OVT	1	1126.2	<1	45.4	<1	18.9	<1

APPENDIX 3: Continued

Source of Variation	DF	L		S		V	
		MS	F	MS	F	MS	F
ODT	1	106.4	<1	167.4	1.06	243.6	1.18
VDT	1	625	<1	0.70	<1	10.9	<1
OVL	1	3473.1	2.36	45.8	<1	384.2	1.86
ODL	1	8.5	<1	175	1.11	207.8	1.0
VDL	1	158.5	<1	81.7	<1	1.5	<1
OTL	1	801.36	<1	650.5	4.13+	110.94	<1
VTL	1	2660	1.81	66.9	<1	14.9	<1
DTL	1	1589.3	1.08	118	<1	63.6	<1
OVM	1	964.1	<1	13.7	<1	380.6	1.84
ODM	1	490.2	<1	734.18	4.66+	544.8	2.64
VDM	1	2893.5	1.97	60.9	<1	0.69	<1
OTM	1	1608.7	1.10	0.67	<1	56.4	<1
VTM	1	2772.9	1.89	86.6	<1	111.3	<1
DTM	1	4244.5	2.89	13	<1	2.9	<1
OLM	1	1656.5	1.13	53.2	<1	17.1	<1
VLM	1	222.5	<1	0.15	<1	78.8	<1
DLM	1	7489.4	5.11+	1.2	<1	345	1.69

APPENDIX 3: Continued

Source of Variation	DF	L		S		V	
		MS	F	MS	F	MS	F
TLM	1	5252.6	3.92+	153	<1	1948.5	9.44+++
OVS	2	3979.6	2.71	218.9	1.39	240.7	1.17
ODS	2	365.6	<1	644.4	4.10+	235.2	1.14
VDS	2	516.4	<1	146.6	<1	68.0	<1
OTS	2	908.7	<1	103.4	<1	120.2	<1
VTS	2	1980	1.35	538.2	3.42+	23.2	<1
DTS	2	585.9	<1	44.7	<1	45.4	<1
OLS	2	887.9	<1	80.3	<1	78.4	<1
VLS	2	387.14	<1	157.9	1.0	40	<1
DLS	2	151.9	<1	6.5	<1	47	<1
TLS	2	1703.2	1.16	97.7	<1	484.31	2.35
OMS	2	619.74	<1	108.8	<1	146.9	<1
VMS	2	1128.8	<1	49.2	<1	167.1	<1
DMS	2	569.2	<1	8.3	<1	542.7	2.63
TMS	2	1300.9	<1	243.9	1.55	621.9	3.01
LMS	2	598.3	<1	108.4	<1	80.7	<1
OVDT	1	333.7	<1	0.2	<1	129.9	<1

APPENDIX 3: Continued

Source of Variation	DF	L		S		V	
		MS	F	MS	F	MS	F
OVDL	1	643	<1	3.4	<1	15.7	<1
OVTL	1	409.7	<1	80.6	<1	5.8	<1
ODTL	1	370.5	<1	386.6	2.49	8.5	<1
VDTL	1	14.7	<1	66.7	<1	386.78	1.87
OVDM	1	2527.6	1.72	7.7	<1	0.02	<1
OVTM	1	441.3	<1	453.9	2.88	20.5	<1
ODTM	1	2952.1	2.01	79.4	<1	38.2	<1
VDTM	1	740.7	<1	4.08	<1	104.9	<1
OVLM	1	1440.2	<1	209.9	1.33	108.68	<1
ODLM	1	4591.2	3.13	8.24	<1	802.3	3.89+
VDLM	1	70.7	<1	868.0	5.52+	360.4	1.74
OTLM	1	128.3	<1	1.7	<1	23.4	<1
VTLM	1	621.2	<1	49.0	<1	312.7	1.51
DTLM	1	1162.8	<1	114.4	<1	1.64	<1
OVDS	2	42.4	<1	78.8	<1	14.1	<1
OVTS	2	690.2	<1	199.8	1.91	90.9	<1
ODTS	2	2806.7	1.91	56.2	<1	206.8	1.0

APPENDIX 3: Continued

Source of Variation	DF	L		S		V	
		MS	F	MS	F	MS	F
VDTS	2	475.2	<1	113.6	<1	21.3	<1
OVLS	2	1301.4	<1	389.2	2.16	192.8	<1
ODLS	2	632.3	<1	49.2	<1	227.8	1.10
VDLS	2	1426.6	<1	462.5	2.94	226.1	1.09
OTLS	2	1853	1.26	48.3	<1	10.3	<1
VTLS	2	1997.2	1.36	158.3	1.0	66.14	<1
DTLS	2	4867	3.32+	583.1	3.70+	491.8	2.38
OVMS	2	545.3	<1	616.7	3.92+	149.0	<1
ODMS	2	383	<1	189.6	1.20	638.1	3.09
VDMS	2	156.8	<1	55.0	<1	179.0	<1
OTMS	2	1436.4	<1	148.4	<1	76.4	<1
VTMS	2	1823.2	1.24	52.4	<1	16.4	<1
DTMS	2	30	<1	185.3	1.17	150.3	<1
OLMS	2	46	<1	66.8	<1	65.3	<1
VLMS	2	2109.2	1.44	7.0	<1	229.8	1.11
DLMS	2	568.5	<1	73.5	<1	244.6	1.78
TLMS	2	1143.9	<1	23.4	<1	363.6	1.76

APPENDIX 3: Continued

Source of Variation	DF	L		S		V	
		MS	F	MS	F	MS	F
OVDTL	1	509.2	<1	22.4	<1	44.9	<1
OVDTM	1	2154.2	1.47	40.7	<1	43.2	<1
OVDLM	1	222.3	<1	109.6	<1	99.7	<1
OVTLM	1	3267.1	2.23	508.7	3.23	180.4	<1
ODTLM	1	1816.2	1.24	6.2	<1	35.6	<1
VDTLM	1	216.1	<1	15.6	<1	264.9	1.28
OVDTS	2	20.2	<1	5.1	<1	361.1	1.75
OVDLS	2	1605.7	1.09	91.6	<1	190.9	<1
OVTLS	2	219.7	<1	27.3	<1	66.3	<1
ODTLS	2	705.9	<1	36.9	<1	226.4	1.09
VDTLS	2	1210.5	<1	202.9	1.29	755.0	3.66+
OVDMS	2	95.4	<1	115.6	<1	262.8	1.27
OVTMS	2	2349.5	1.60	28.6	<1	69.7	<1
ODTMS	2	2030.4	1.38	139.4	<1	22.6	<1
VDTMS	2	979	<1	235.5	1.50	49.7	<1
OVLMS	2	409.8	<1	116.0	<1	58.5	<1
ODLMS	2	1462.8	<1	119.0	<1	114.7	<1

APPENDIX 3: Continued

Source of Variation	DF	L		S		V	
		MS	F	MS	F	MS	F
VDLMS	2	334.8	<1	53.7	<1	255.4	1.24
OTLMS	2	1042.2	<1	8.5	<1	177.2	<1
VTLMS	2	2745.3	1.87	207.3	1.31	99.2	<1
DTLMS	2	1133.6	<1	125.6	<1	284.1	1.38
OVDTLM	1	2119.1	1.44	716.2	4.55	481.4	2.33
OVDTLS	2	201.5	<1	99.9	<1	46.3	<1
OVDTMS	2	268.5	<1	46.2	<1	6.31	<1
OVDLMS	2	8.9	<1	90.6	<1	331.4	1.61
OVTLMS	2	1767.8	1.20	243.8	1.55	49.2	<1
ODTLMS	2	1985.6	1.83	125.6	<1	521.3	2.5
VDTLMS	2	685.6	<1	1.36	<1	122.8	<1
OVDTLMS	2	2458.5	1.67	136.10	<1	13.10	<1
Error (2)	378	1465.63	<1	157.26	<1	206.32	<1
TOTAL	575						

\+ Significant at 0.05 probability level
++ Significant at 0.01 probability level
+++ Significant at 0.005 probability level (highly significant)

APPENDIX 4: ANALYSIS OF VARIANCE OF THE LATERAL REACTION WITH OVERLAP.

Source of variation	DF	MS	F
Replicate (R)	2	1346.8	<1
Soil (S)	2	1822.5	<1
Error (1)	4	3274	
Subtotal (1)	8		
Make (M)	1	1.8	<1
Lift (L)	1	47.8	<1
Thickness (T)	1	64.8	<1
Depth (D)	1	11613.0	52.18+++
Velocity (V)	1	2269.1	10.2+++
VD	1	852.8	3.83
VT	1	51.2	<1
DT	1	2.8	<1
VL	1	94.1	<1
DL	1	41.2	<1
TL	1	8.4	<1
VM	1	164.7	<1
DM	1	193.7	<1
TM	1	62.3	<1
LM	1	368.1	1.65
VS	2	78.4	<1
DS	2	511.8	2.3
TS	2	147.9	<1
LS	2	152.6	<1
MS	2	176.7	<1
VDT	1	0.07	<1

APPENDIX 4: Continued

Source of variation	DF	MS	
VDL	1	25.8	<1
VTL	1	0.3	<1
DTL	1	38.7	<1
VDM	1	56.0	<1
VTM	1	72.0	<1
DTM	1	14.0	<1
VLM	1	99.0	<1
DLM	1	1.6	<1
TLM	1	93.6	<1
VDS	2	17.6	<1
VTS	2	96.0	<1
DTS	2	15.3	<1
VLS	2	34.6	<1
DLS	2	41.0	<1
TLS	2	33.6	<1
VMS	2	237.7	1.06
DMS	2	92.2	<1
TMS	2	51.5	<1
LMS	2	158.6	<1
VDTL	1	83.2	<1
VDTM	1	35.3	<1
VDLM	1	797.3	3.58
VTLM	1	120.0	<1
DTLM	1	86.9	<1
VDTS	2	82.9	<1
VDLS	2	271.0	1.21
VTLS	2	134.8	<1
DTLS	2	165.0	<1

APPENDIX 4: Contined

Source of variation	DF	MS	F
VDMS	2	161.5	<1
VTMS	2	63.0	<1
DTMS	2	20.0	<1
VLMS	2	43.4	<1
DLMS	2	48.1	<1
TLMS	2	10.8	<1
VDTLM	1	471.8	2.12
VDTLS	2	221.8	<1
VDTMS	2	237.4	1.06
VDLMS	2	52.1	<1
VTLMS	2	11.4	<1
DTLMS	2	124.1	<1
VDTLMS	2	55.1	<1
Error (2)	190	222.55	-
TOTAL	287		

+ Significant at 0.05 probability level.
++ Significant at 0.01 probability level.
+++ Significant at 0.005 probability level (highly significant).

SYMBOLS USED IN APPENDICES 5 THROUGH 10.

Factor/Level	Description	Symbol
Soil 1	Silty clay loam	S1
Soil 2	Clay loam	S2
Soil 3	Clay	S3
Make 1	---	M1
Make 2	---	M2
Low lift	1 1/64"	L1
High lift	1 1/4"	L2
Thin	1/4"	T1
Thick	5/16"	T2
Depth of cut	3"	D1
Depth of cut	4"	D2
Velocity of travel	3 mph	V1
Velocity of travel	6 mph	V2
Without overlap	---	O1
With overlap	2" overlap	O2

APPENDIX NO. 5 DRAFT (LB) - REPLICATE NO. 1

				D1				D2			
				V1		V2		V1		V2	
S	M	L	T	O1	O2	O1	O2	O1	O2	O1	O2
S1	M1	L1	T1	140.4	126.8	179.1	147.9	204.3	139.7	387.6	169.6
			T2	95.0	86.8	150.6	115.1	191.5	135.4	332.4	176.8
		L2	T1	161.7	90.1	147.9	140.8	157.3	139.5	347.8	238.7
			T2	165.2	107.0	241.7	124.3	237.7	166.0	370.5	229.7
	M2	L1	T1	127.7	88.2	160.2	80.3	221.2	138.6	236.8	105.6
			T2	139.3	70.1	157.5	96.5	177.7	120.8	426.1	192.3
		L2	T1	149.6	100.3	161.6	111.7	165.3	119.9	260.1	170.4
			T2	147.8	98.6	177.9	115.8	227.4	119.8	353.3	130.3
S2	M1	L1	T1	158.7	103.2	213.4	167.9	312.2	192.1	394.1	260.4
			T2	150.2	134.9	194.4	143.2	250.3	158.2	344.4	251.0
		L2	T1	151.0	102.1	233.6	159.4	217.1	176.1	343.3	279.8
			T2	162.5	130.8	223.9	157.8	302.3	190.8	347.6	269.2
	M2	L1	T1	129.1	129.9	202.2	114.2	227.4	165.0	334.7	191.3
			T2	132.9	102.5	173.3	148.3	264.3	197.6	320.2	240.5
		L2	T1	159.6	107.8	208.0	154.8	249.9	188.6	385.1	216.9
			T2	169.6	101.9	161.0	132.4	246.9	201.2	310.4	261.7
S3	M1	L1	T1	131.3	70.2	162.0	117.7	216.2	106.7	249.5	129.7
			T2	128.2	85.3	137.0	101.7	245.9	155.8	280.9	197.3
		L2	T1	145.2	73.3	140.4	130.6	217.6	149.0	391.1	175.0
			T2	150.5	99.4	137.9	158.2	244.8	175.9	287.6	128.8
	M2	L1	T1	123.1	74.0	110.9	110.6	165.7	127.8	235.7	178.3
			T2	130.0	98.4	150.5	104.2	199.9	180.5	291.4	245.5
		L2	T1	140.8	69.7	156.6	108.3	203.7	115.2	192.6	154.2
			T2	107.5	106.8	185.4	127.9	214.9	165.7	349.6	150.6

APPENDIX NO. 5 DRAFT(LB) - REPLICATE NO. 2

				D1				D2			
				V1		V2		V1		V2	
S	M	L	T	O1	O2	O1	O2	O1	O2	O1	O2
S1	M1	L1	T1	121.3	61.4	150.4	106.5	198.0	152.8	231.4	187.1
			T2	117.4	99.4	177.0	120.1	217.8	106.1	321.9	156.2
		L2	T1	108.2	78.0	198.7	116.6	212.2	179.3	307.4	166.6
			T2	143.9	125.7	180.8	133.5	211.5	142.6	277.3	215.5
	M2	L1	T1	80.9	65.3	123.4	119.2	140.0	115.0	233.8	158.1
			T2	126.1	94.9	108.8	138.7	223.3	147.7	141.6	143.9
		L2	T1	89.4	85.5	180.7	116.6	144.5	142.1	235.2	170.6
			T2	96.1	97.6	153.8	141.1	201.0	115.5	320.4	166.5
S2	M1	L1	T1	170.3	123.6	174.1	153.8	259.6	174.5	425.6	284.2
			T2	244.6	118.6	222.8	162.7	261.9	168.0	328.0	301.5
		L2	T1	177.2	157.9	232.9	260.3	262.1	210.2	320.5	248.6
			T2	217.5	148.4	222.4	236.1	278.1	240.1	350.8	271.9
	M2	L1	T1	192.1	183.8	133.4	248.9	232.0	165.1	274.4	256.2
			T2	170.1	151.9	172.6	229.5	270.1	199.4	282.4	230.9
		L2	T1	160.4	158.5	285.6	185.3	226.5	171.5	404.7	247.8
			T2	210.9	179.6	181.0	241.2	240.8	194.7	331.9	320.1
S3	M1	L1	T1	157.6	140.7	194.3	179.1	369.9	212.3	406.0	283.5
			T2	192.5	124.6	274.8	171.8	292.0	194.2	436.3	342.9
		L2	T1	178.0	105.5	282.0	196.4	265.9	262.7	442.3	359.1
			T2	222.9	160.6	323.0	153.2	248.6	203.9	309.9	263.3
	M2	L1	T1	175.9	110.3	235.0	140.2	249.0	215.8	283.1	238.7
			T2	166.8	146.3	174.9	233.6	359.9	136.0	444.4	396.3
		L2	T1	182.8	171.8	154.8	162.5	315.8	223.1	484.2	305.6
			T2	210.4	110.0	224.6	152.2	331.6	207.5	504.1	259.1

APPENDIX NO. 5 DRAFT(LB) - REPLICATE NO. 3

				D1				D2			
				V1		V2		V1		V2	
S	M	L	T	O1	O2	O1	O2	O1	O2	O1	O2
S1	M1	L1	T1	155.8	126.9	215.6	120.8	251.7	200.6	318.2	223.3
			T2	123.3	126.3	241.0	177.6	236.8	386.2	265.7	183.7
		L2	T1	159.6	119.8	219.3	201.6	238.6	198.9	282.1	212.1
			T2	162.6	100.9	241.6	146.1	239.0	127.9	368.3	194.2
	M2	L1	T1	138.4	164.4	175.4	126.9	167.9	156.2	226.3	196.1
			T2	131.6	118.1	205.0	142.2	264.8	160.7	279.1	281.9
		L2	T1	134.8	128.5	211.5	141.0	251.6	190.8	361.1	237.6
			T2	171.6	139.9	204.8	139.1	331.7	138.3	352.0	258.0
S2	M1	L1	T1	211.1	143.9	237.3	312.8	292.6	218.5	377.1	258.0
			T2	252.2	184.3	290.8	235.8	278.0	217.7	351.4	231.9
		L2	T1	232.9	145.9	330.0	212.6	274.5	223.5	433.6	252.3
			T2	223.6	161.8	307.4	213.3	312.0	207.3	429.4	299.7
	M2	L1	T1	244.6	208.0	265.5	163.3	264.6	178.0	285.1	230.0
			T2	409.6	273.1	268.5	189.1	309.1	232.4	350.9	261.5
		L2	T1	237.3	225.3	296.7	249.6	316.0	193.6	377.9	293.5
			T2	241.3	143.3	371.0	194.1	299.2	229.5	342.0	257.5
S3	M1	L1	T1	132.8	164.6	137.4	142.0	255.4	216.9	253.4	240.3
			T2	118.3	100.7	114.5	134.2	233.2	288.5	298.8	253.9
		L2	T1	141.9	79.2	259.9	167.4	179.3	188.5	361.3	207.0
			T2	190.9	98.6	158.3	123.0	281.1	209.7	253.0	307.6
	M2	L1	T1	183.1	125.3	195.6	131.0	202.1	165.9	179.1	200.4
			T2	199.5	163.0	220.2	128.8	278.6	200.1	275.7	215.1
		L2	T1	111.8	98.3	158.8	112.9	273.6	170.3	275.2	225.6
			T2	190.3	124.4	168.5	97.8	192.4	152.2	342.0	216.4

APPENDIX NO. 6 SIDE DRÁFT (LB) - REPLICATE NO. 1

				D1				D2			
				V1		V2		V1		V2	
S	M	L	T	O1	O2	O1	O2	O1	O2	O1	O2
S1	M1	L1	T1	-7.2	19.1	-8.3	18.3	-6.7	18.5	-1.8	26.9
			T2	-14.6	25.9	0.1	17.6	-11.1	22.1	-3.3	39.3
		L2	T1	3.8	18.8	0.5	19.9	14.0	25.1	-6.5	51.7
			T2	-7.3	9.3	7.7	24.5	-8.0	25.7	2.7	51.1
	M2	L1	T1	0.5	22.4	-2.5	10.3	-7.7	26.8	-6.3	8.3
			T2	4.7	19.4	-9.9	14.8	1.0	29.3	-8.0	36.1
		L2	T1	9.0	22.5	-6.8	16.1	9.3	18.5	4.6	30.6
			T2	6.6	16.0	-4.3	13.8	10.1	27.3	-9.8	39.8
S2	M1	L1	T1	-14.9	19.1	13.1	8.0	-1.7	45.5	4.3	45.7
			T2	-6.5	32.0	-17.3	20.0	-2.9	27.3	-5.8	46.5
		L2	T1	-19.4	15.3	15.3	26.7	-26.5	25.9	7.4	41.3
			T2	6.8	14.7	-2.4	32.7	4.0	25.9	-22.6	45.9
	M2	L1	T1	-1.1	31.6	9.7	25.2	5.5	41.1	0.0	40.7
			T2	-6.3	9.2	6.9	22.4	6.0	30.3	-25.5	33.8
		L2	T1	-6.3	16.3	8.1	32.9	-12.5	34.6	15.5	47.8
			T2	10.3	20.5	-23.9	5.0	-19.7	40.7	-15.5	41.4
S3	M1	L1	T1	34.2	25.1	1.3	26.5	15.3	12.4	3.4	37.9
			T2	1.6	19.7	-6.7	14.8	-6.4	23.0	-0.6	62.4
		L2	T1	-2.6	9.5	13.6	12.1	-0.7	25.8	-8.7	14.1
			T2	-24.3	27.2	10.6	59.5	-14.1	64.6	-11.0	10.4
	M2	L1	T1	13.1	17.0	-9.0	42.9	-19.0	59.9	-6.0	44.6
			T2	0.5	19.1	-26.0	18.7	2.8	29.7	-28.8	59.0
		L2	T1	8.1	27.3	-2.7	22.4	-2.7	30.8	0.9	36.0
			T2	-17.0	32.8	-5.9	29.4	-20.4	10.6	6.5	5.2

APPENDIX NO. 6 SIDE DRÀFT (LB) - REPLICATE NO. 2

				D1				D2			
				V1		V2		V1		V2	
S	M	L	T	O1	O2	O1	O2	O1	O2	O1	O2
S1	M1	L1	T1	-0.6	17.5	-15.1	16.4	0.1	28.0	-29.9	28.2
			T2	-1.7	12.0	3.6	18.5	-3.1	0.9	12.8	14.8
		L2	T1	-2.0	10.0	-4.5	12.7	7.7	23.4	-4.5	9.1
			T2	-15.5	24.4	-6.6	15.6	-1.5	25.5	-9.5	37.5
	M2	L1	T1	-13.7	15.3	3.3	7.5	-1.2	20.2	-7.2	28.5
			T2	-2.9	11.4	12.9	33.8	9.2	32.2	23.6	13.4
		L2	T1	-1.4	15.5	8.8	12.6	-9.0	19.6	4.5	21.7
			T2	-6.4	16.5	-14.3	33.3	-19.2	16.4	-18.2	36.1
S2	M1	L1	T1	-3.0	3.7	-26.0	-2.4	-15.5	2.5	-23.0	32.8
			T2	5.4	-2.3	3.0	5.0	-5.8	4.7	-9.6	24.2
		L2	T1	4.0	-5.3	-23.3	25.7	-3.9	10.7	-20.2	15.3
			T2	-9.5	-0.9	-15.3	13.5	-27.7	31.8	-16.0	24.7
	M2	L1	T1	-7.7	26.4	-9.1	32.2	1.9	24.0	-9.2	32.9
			T2	-5.1	10.3	-31.2	14.7	-6.4	8.3	-16.2	19.8
		L2	T1	-1.5	22.2	14.4	-10.8	-11.6	3.3	8.3	27.8
			T2	-4.9	18.9	-14.3	18.0	-5.3	7.9	-6.5	23.4
S3	M1	L1	T1	10.2	24.2	-0.5	7.8	21.0	41.8	13.2	66.5
			T2	14.9	41.0	20.5	17.4	-21.0	26.0	21.8	53.4
		L2	T1	20.5	24.1	41.2	43.7	46.8	70.4	46.1	88.2
			T2	35.6	40.6	25.7	32.9	9.2	48.4	-25.2	50.2
	M2	L1	T1	33.4	16.9	-1.9	38.1	18.6	40.4	-24.6	39.3
			T2	21.4	39.2	-25.8	47.4	31.8	6.1	-8.4	80.8
		L2	T1	-10.0	26.9	0.7	29.7	26.7	29.4	9.4	59.7
			T2	4.0	18.5	3.4	45.3	7.3	53.9	-18.1	56.7

APPENDIX NO. 6 SIDE DRAFT (LB) - REPLICATE NO. 3

				D1				D2			
				V1		V2		V1		V2	
S	M	L	T	O1	O2	O1	O2	O1	O2	O1	O2
S1	M1	L1	T1	1.1	21.2	-0.6	15.6	12.2	11.5	-2.3	34.6
			T2	4.5	19.6	9.7	35.0	14.5	44.0	10.0	26.4
		L2	T1	11.8	30.7	-1.1	30.1	3.4	28.8	-10.7	29.1
			T2	8.6	27.0	-1.7	28.3	7.5	17.6	5.3	41.3
	M2	L1	T1	3.8	11.9	-9.3	24.0	8.9	29.2	2.3	27.9
			T2	-6.1	19.6	18.5	17.5	21.0	27.3	12.7	38.9
		L2	T1	5.1	35.9	5.7	22.0	32.8	38.1	17.3	40.6
			T2	8.4	37.8	17.0	20.0	11.8	21.9	7.5	43.6
S2	M1	L1	T1	-0.9	21.9	8.6	52.5	-5.7	36.2	16.3	56.5
			T2	9.7	29.9	13.3	33.6	-11.1	42.1	-3.7	37.9
		L2	T1	14.2	32.4	17.4	41.3	3.8	46.4	27.4	41.6
			T2	8.2	-1.4	6.7	39.2	-6.1	47.2	17.7	76.3
	M2	L1	T1	3.6	32.6	5.7	28.9	4.4	38.9	69.0	46.9
			T2	15.9	57.9	13.7	34.6	13.1	45.2	13.1	52.6
		L2	T1	12.4	54.9	10.9	22.4	14.9	38.3	18.3	74.1
			T2	-8.1	24.4	11.0	38.0	-9.6	45.2	-3.6	46.7
S3	M1	L1	T1	19.4	30.9	13.1	19.2	19.0	40.2	-13.9	42.2
			T2	5.4	13.5	2.9	20.0	-3.1	72.4	15.5	26.2
		L2	T1	0.7	12.6	13.3	29.7	-7.0	26.2	18.8	46.8
			T2	19.2	11.7	40.2	7.2	8.5	30.3	-18.2	70.5
	M2	L1	T1	8.4	20.2	10.5	19.7	23.5	31.7	-5.4	27.7
			T2	19.3	26.1	3.5	19.5	32.8	45.3	23.3	37.8
		L2	T1	13.4	4.7	8.3	20.4	30.4	34.5	4.9	29.5
			T2	18.6	7.6	4.6	-5.0	7.0	31.3	17.2	41.8

APPENDIX NO. 7 VERTICAL REACTION(LB) - REPLICATE NO. 1

S	M	L	T	D1				D2			
				V1		V2		V1		V2	
				O1	O2	O1	O2	O1	O2	O1	O2
S1	M1	L1	T1	-32.6	-23.4	-36.3	-38.6	-27.4	-41.4	-105.5	-47.6
			T2	-8.7	-11.9	-2.7	8.1	-46.2	-30.6	-75.5	-38.2
		L2	T1	5.0	7.1	-19.7	-35.4	-33.8	-26.7	-96.4	-46.4
			T2	-21.8	14.4	6.3	-1.6	-43.6	-27.1	-62.9	-55.2
	M2	L1	T1	-28.6	-10.6	-30.6	-11.1	-73.1	-28.4	-75.0	-32.8
			T2	-30.2	-16.1	-31.6	-8.5	-53.3	-18.7	-98.5	-56.9
		L2	T1	-32.6	-5.2	-11.9	-25.6	-41.9	-30.9	-65.4	-39.0
			T2	-3.8	-3.3	-21.3	-30.2	-53.3	-24.5	-75.0	-35.8
S2	M1	L1	T1	-33.5	-18.7	-56.2	-38.0	-101.0	-52.0	-114.1	-62.7
			T2	-29.6	-28.1	-41.6	-32.5	-64.8	-42.6	-91.5	-71.8
		L2	T1	-5.5	-17.7	-46.9	-38.3	-42.0	-40.7	-91.7	-67.9
			T2	-1.2	4.4	-37.0	-27.2	-57.6	-58.4	-60.0	-59.7
	M2	L1	T1	-27.9	-18.4	-43.5	-38.2	-59.7	-28.5	-83.0	-51.3
			T2	-28.3	-19.1	-48.0	-34.1	-65.4	-54.6	-93.9	-74.0
		L2	T1	-26.3	-18.6	-47.0	-43.4	-67.3	-41.6	-89.5	-64.8
			T2	-19.1	-15.2	-3.3	-37.9	-54.2	-55.8	-82.5	-63.2
S3	M1	L1	T1	-34.1	-8.3	-42.3	-33.3	-65.2	-37.5	-72.0	-45.2
			T2	-14.3	10.0	-14.0	-17.2	-43.3	-43.3	-78.6	-62.5
		L2	T1	-21.8	3.4	-1.2	-9.7	-46.3	-26.8	-74.8	-52.7
			T2	18.7	1.0	-10.3	-28.8	-35.1	-28.4	-56.9	-24.7
	M2	L1	T1	0.4	25.1	9.1	-20.9	-54.1	-21.2	-48.1	-44.9
			T2	3.0	-4.7	-35.8	-13.9	-51.9	-63.9	-94.5	-68.4
		L2	T1	5.0	-5.6	-15.3	-17.4	-57.4	-27.5	-42.8	-41.8
			T2	7.0	0.6	-25.9	-12.2	-50.1	-37.2	-49.8	-31.8

APPENDIX NO. 7 VERTICAL REACTION(LB) - REPLICATE NO. 2

				D1				D2			
				V1		V2		V1		V2	
S	M	L	T	O1	O2	O1	O2	O1	O2	O1	O2
S1	M1	L1	T1	-16.6	-18.5	-16.4	-20.6	-55.3	-38.9	-65.6	-52.9
			T2	5.0	4.8	-35.6	-25.5	-57.6	-26.7	-82.3	-39.2
		L2	T1	-5.4	-0.8	-6.9	-19.9	-36.6	-34.5	-65.8	-33.2
			T2	33.0	6.5	-8.1	-7.1	-43.5	-20.7	-40.7	-47.4
	M2	L1	T1	-22.3	-16.8	-18.0	-18.4	-36.5	-27.5	-72.6	-42.3
			T2	-6.6	-13.5	-33.2	-33.3	-63.1	-24.2	-29.3	-39.9
		L2	T1	-7.4	-6.5	-42.1	-17.5	-33.5	-34.2	-69.6	-31.6
			T2	5.2	-11.5	-25.8	-16.6	-23.5	-21.0	-81.3	-45.0
S2	M1	L1	T1	7.5	3.2	4.6	-3.0	-55.1	-25.1	-105.7	-67.2
			T2	-10.4	10.5	-4.5	0.2	-39.0	-14.9	-74.9	-67.3
		L2	T1	9.1	14.2	-0.9	-0.4	-40.3	-10.3	-58.9	-29.1
			T2	7.6	21.9	4.8	-3.5	-47.2	-18.2	-51.3	-30.1
	M2	L1	T1	23.7	29.8	-9.1	-12.7	-37.6	-8.6	-68.7	-43.5
			T2	-4.1	17.3	-17.7	15.1	-60.3	-22.6	-54.7	-50.2
		L2	T1	9.1	18.1	-4.0	-5.4	-39.5	-6.6	-99.1	-40.9
			T2	-7.4	12.3	8.6	-22.6	-24.3	-9.4	-83.0	-57.8
S3	M1	L1	T1	-31.1	-18.2	-53.4	-33.4	-99.6	-65.2	-114.2	-79.6
			T2	-47.8	-13.0	-56.9	-20.6	-86.3	-63.7	-122.3	-89.1
		L2	T1	-27.5	-21.4	-57.8	-7.9	-67.8	-86.3	-116.6	-106.1
			T2	-22.1	-2.9	-23.5	-10.1	-54.0	-53.7	-53.2	-60.9
	M2	L1	T1	-41.6	2.1	-57.4	-25.3	-81.8	-69.7	-99.0	-71.9
			T2	-30.2	-16.2	-24.6	-67.3	-106.0	-45.1	-142.0	-118.5
		L2	T1	-13.9	-26.0	-2.6	-25.7	-109.3	-50.3	-146.7	-81.9
			T2	-17.4	-2.6	-7.2	-13.1	-82.1	-44.1	-114.1	-85.4

APPENDIX NO. 7 VERTICAL REACTION (LB) - REPLICATE NO. 3

				D1				D2			
				V1		V2		V1		V2	
S	M	L	T	O1	O2	O1	O2	O1	O2	O1	O2
S1	M1	L1	T1	-13.5	-25.3	-50.2	-24.2	-62.9	-26.3	-82.5	-48.3
			T2	-13.8	-5.1	-43.5	-23.1	-56.2	-1.8	-77.1	-38.3
		L2	T1	-24.2	-1.5	-28.3	-38.1	-45.8	-36.2	-68.1	-44.3
			T2	0.8	-7.7	-19.1	-9.7	-28.2	-19.9	-72.3	-32.4
	M2	L1	T1	-14.0	-23.6	-33.2	-16.3	-49.6	-28.7	-76.7	-36.6
			T2	-11.4	-10.0	-40.0	-13.2	-67.4	-22.1	-77.7	-46.8
		L2	T1	2.8	-9.2	-44.5	-29.2	-64.7	-30.0	-75.7	-56.6
			T2	-23.3	-22.8	-28.4	-2.5	-63.3	-27.7	-76.4	-56.0
S2	M1	L1	T1	-35.7	-5.1	-31.7	-42.3	-60.3	-40.2	-85.2	-58.9
			T2	2.9	13.5	-12.8	-11.8	-44.5	-42.2	-78.0	-52.0
		L2	T1	-18.5	-11.6	-46.1	-11.0	-57.4	-21.3	-57.2	-31.4
			T2	19.2	10.5	-32.6	5.4	-57.0	-17.2	-74.7	-52.6
	M2	L1	T1	-31.5	-10.2	17.8	-10.7	-61.3	-33.2	-36.7	-38.7
			T2	-53.1	-19.9	-37.8	-14.1	-58.9	-50.4	-71.7	-61.2
		L2	T1	-34.7	-28.6	2.3	-19.2	-62.3	-53.6	-83.6	-80.2
			T2	18.5	8.6	-29.3	-12.3	-45.3	-43.9	-85.6	-35.9
S3	M1	L1	T1	-1.6	2.9	13.1	7.9	-40.0	-23.3	-5.2	-18.7
			T2	33.0	15.2	30.5	39.6	15.9	-23.3	-3.8	-1.9
		L2	T1	25.1	16.2	25.4	40.8	9.5	15.0	-37.6	-8.6
			T2	39.0	34.6	12.8	47.9	19.8	8.7	5.9	15.4
	M2	L1	T1	56.4	61.6	39.5	37.3	32.0	18.5	15.4	16.6
			T2	5.7	32.4	37.6	22.3	-37.5	-5.5	9.3	17.4
		L2	T1	47.0	24.0	40.7	38.2	-22.8	20.9	-9.2	17.6
			T2	52.8	36.7	37.0	16.2	1.3	1.7	-46.8	-2.0

APPENDIX NO. 8 F1(LB) - REPLICATE NO. 1

				D1				D2			
				V1		V2		V1		V2	
S	M	L	T	O1	O2	O1	O2	O1	O2	O1	O2
S1	M1	L1	T1	180.1	141.9	220.3	161.5	241.4	154.0	440.5	187.3
			T2	115.3	107.3	185.7	138.7	214.9	150.8	373.3	196.1
		L2	T1	206.2	113.2	191.3	164.6	174.3	157.3	391.3	281.7
			T2	196.1	135.3	299.3	145.4	273.6	192.9	431.6	261.5
	M2	L1	T1	152.8	112.3	182.7	94.1	243.3	151.7	274.0	114.7
			T2	164.5	84.8	194.3	113.2	195.1	141.3	471.7	219.5
		L2	T1	169.1	118.7	198.1	139.0	178.0	136.1	286.0	198.6
			T2	182.1	122.4	215.0	137.5	250.8	141.3	400.9	196.0
S2	M1	L1	T1	198.1	127.7	255.3	203.3	343.5	215.9	450.0	295.7
			T2	197.0	155.9	255.3	190.2	286.5	195.8	395.0	295.4
		L2	T1	202.1	127.7	293.7	189.3	261.0	213.8	391.7	328.2
			T2	215.5	160.7	277.4	192.6	350.5	231.5	415.6	300.8
	M2	L1	T1	171.7	160.5	233.9	144.9	269.1	195.1	389.5	208.1
			T2	171.8	130.7	213.6	184.8	298.1	229.5	369.5	265.9
		L2	T1	198.0	149.5	251.5	191.3	289.6	216.4	445.9	261.3
			T2	205.7	125.4	206.5	162.6	289.4	233.5	364.3	297.6
S3	M1	L1	T1	153.6	103.6	203.2	153.7	240.4	129.0	280.7	157.9
			T2	184.8	137.7	166.1	142.4	305.9	186.9	330.5	229.6
		L2	T1	179.6	100.3	188.8	174.6	252.9	180.5	468.8	215.0
			T2	204.2	130.9	180.3	200.1	318.0	211.8	338.9	152.0
	M2	L1	T1	190.4	116.5	155.7	139.4	194.3	160.8	287.1	209.6
			T2	184.5	122.6	187.3	143.4	228.3	220.3	336.3	309.2
		L2	T1	197.6	86.1	223.6	137.2	236.0	159.9	233.8	171.1
			T2	141.0	154.5	230.6	179.3	248.4	203.3	426.9	177.5

F1-VALUE FOR CALCULATION OF PITCHING MCMENT AS DEFINED BY HARRISON (12)

APPENDIX NO. 8 F1(LB) - REPLICATE NO. 2

				D1				D2			
				V1		V2		V1		V2	
S	M	L	T	O1	O2	O1	O2	O1	O2	O1	O2
S1	M1	L1	T1	143.8	61.5	188.4	124.9	209.5	159.7	249.2	196.9
			T2	152.7	114.9	196.2	128.9	230.1	104.3	364.2	179.1
		L2	T1	123.3	86.2	251.4	130.4	246.5	209.0	359.8	173.0
			T2	193.6	153.6	216.3	173.4	259.8	151.8	305.1	236.9
	M2	L1	T1	92.6	63.2	135.6	119.7	146.0	115.8	250.4	167.1
			T2	153.3	97.0	103.6	158.4	231.5	162.9	150.5	156.7
		L2	T1	95.1	92.2	209.0	131.8	156.5	146.2	259.5	184.7
			T2	111.7	103.6	191.4	154.1	229.4	116.9	367.2	172.3
S2	M1	L1	T1	202.0	144.0	194.8	180.8	233.3	192.8	454.6	312.9
			T2	281.8	145.2	256.2	190.2	279.5	197.4	360.6	316.9
		L2	T1	216.8	184.3	272.9	297.3	275.7	234.7	352.5	280.0
			T2	250.2	173.7	275.6	282.4	310.7	268.8	413.9	314.2
	M2	L1	T1	230.4	214.7	170.1	292.5	261.3	193.9	309.0	275.8
			T2	194.8	181.4	196.1	276.7	285.4	220.2	317.5	255.6
		L2	T1	198.3	185.4	337.3	223.9	247.7	191.9	423.6	269.1
			T2	245.0	205.6	226.5	273.0	272.5	218.2	365.0	343.7
S3	M1	L1	T1	178.9	179.0	240.1	214.8	396.9	221.8	461.7	321.9
			T2	231.2	150.3	316.9	204.6	323.3	218.4	485.4	375.3
		L2	T1	206.2	135.7	326.2	228.7	302.3	278.8	508.3	413.7
			T2	280.2	204.2	398.1	180.5	273.8	241.3	368.1	287.8
	M2	L1	T1	210.5	130.1	264.8	167.7	264.4	229.9	319.5	264.5
			T2	198.5	173.6	206.7	267.1	381.2	147.3	480.4	428.9
		L2	T1	218.2	212.3	187.2	188.1	345.3	250.2	537.0	336.1
			T2	243.8	135.0	250.0	189.4	365.8	235.3	573.9	282.5

F1-VALUE FOR CALCULATION OF PITCHING MOMENT AS DEFINED BY HARRISON(12)

APPENDIX NO. 8 F1(LB) - REPLICATE NO. 3

				D1				D2			
				V1		V2		V1		V2	
S	M	L	T	O1	O2	O1	O2	O1	O2	O1	O2
S1	M1	L1	T1	181.8	134.3	246.5	142.2	282.7	228.3	352.3	236.2
			T2	142.8	151.2	266.8	195.1	257.7	416.6	310.8	201.6
		L2	T1	184.1	141.4	262.6	229.0	261.5	212.8	311.1	240.8
			T2	196.5	119.4	287.1	178.4	278.2	140.0	411.4	229.6
	M2	L1	T1	157.2	172.9	200.0	150.7	188.0	173.1	241.8	211.2
			T2	157.7	126.1	232.2	176.1	293.0	185.1	306.8	313.6
		L2	T1	169.4	155.3	241.3	160.5	275.7	210.0	390.2	252.2
			T2	197.3	156.1	232.3	169.8	354.2	155.6	391.7	282.9
S2	M1	L1	T1	238.4	175.8	289.9	357.2	326.5	239.6	427.1	292.3
			T2	309.1	224.9	351.5	272.8	322.0	244.5	396.4	254.6
		L2	T1	279.1	178.4	372.3	253.7	303.5	262.1	504.0	298.9
			T2	280.4	197.6	373.6	251.9	341.9	242.4	488.4	347.0
	M2	L1	T1	288.1	247.6	337.4	194.5	292.9	207.0	332.0	260.0
			T2	465.7	316.5	334.7	221.0	347.6	248.1	415.1	291.3
		L2	T1	278.4	266.9	352.7	283.6	366.9	207.1	430.6	338.0
			T2	309.0	175.0	436.1	238.1	341.4	262.9	383.1	293.0
S3	M1	L1	T1	157.9	217.2	184.7	179.0	304.7	261.7	319.1	297.2
			T2	163.9	132.6	157.9	174.2	295.8	358.0	374.6	305.8
		L2	T1	182.6	111.2	332.8	219.1	235.8	236.5	432.9	256.7
			T2	254.4	133.2	213.8	178.6	349.3	269.5	311.5	396.7
	M2	L1	T1	245.1	182.5	244.6	183.5	264.2	214.7	247.0	261.4
			T2	259.4	234.8	289.3	169.7	364.1	243.7	341.5	267.8
		L2	T1	161.0	124.3	212.9	155.4	332.4	216.4	335.1	286.6
			T2	260.5	162.3	228.6	134.5	233.8	190.2	398.0	253.3

F1-VALUE FOR CALCULATION OF PITCHING MOMENT AS DEFINED BY HARRISON(12)

APPENDIX NO. 9 (F3-F2) (LB) - REPLICATE NO. 1

				D1				D2			
				V1		V2		V1		V2	
S	M	L	T	O1	O2	O1	C2	O1	C2	C1	O2
S1	M1	L1	T1	7.9	-12.9	7.1	-13.6	9.1	-13.1	1.9	-18.1
			T2	15.8	-10.5	-1.3	-11.7	3.9	-12.5	-7.1	-20.4
		L2	T1	-4.8	-11.4	-5.7	-19.9	-6.8	-17.1	-10.8	-43.3
			T2	2.3	-20.1	-2.0	-17.5	2.1	-17.5	-2.2	-31.3
	M2	L1	T1	-4.6	-16.4	3.0	-7.9	1.3	-12.5	6.6	-4.1
			T2	-10.0	-7.2	-2.3	-10.1	-2.3	-17.5	1.1	-25.7
		L2	T1	-6.7	-9.1	4.8	-10.6	-1.0	-7.8	-3.3	-18.1
			T2	-1.4	-14.3	-1.9	-10.4	-6.1	-14.6	1.6	2.3
S2	M1	L1	T1	10.2	-7.6	3.4	-2.8	5.4	-12.3	4.6	-17.2
			T2	1.2	-15.3	9.0	-9.4	4.5	-10.6	-0.2	-32.6
		L2	T1	6.5	-8.3	-16.6	-22.3	9.4	-19.3	-11.2	-30.2
			T2	-2.6	-18.9	-4.6	-10.5	-2.7	-20.0	12.4	-27.1
	M2	L1	T1	-3.8	-15.7	-3.2	-12.6	0.8	-17.9	1.8	-24.5
			T2	7.1	-7.5	-1.3	-12.7	1.7	-20.2	9.9	-28.0
		L2	T1	6.4	-11.2	-12.3	-16.3	14.5	-19.9	-3.4	-27.3
			T2	-0.4	-9.7	12.9	-2.6	7.2	-23.1	7.9	-30.1
S3	M1	L1	T1	-1.7	-11.7	-1.0	-13.4	2.9	-3.2	-2.5	-6.3
			T2	4.2	-11.0	10.0	-16.3	7.5	-19.1	4.6	-26.0
		L2	T1	-7.7	-6.9	-0.4	-12.8	-5.9	-12.4	9.3	-16.7
			T2	7.3	-13.0	2.2	-26.1	7.1	-21.8	-6.5	-4.1
	M2	L1	T1	-0.4	-10.1	6.6	-13.0	15.0	-15.2	13.4	-17.3
			T2	-0.8	-10.3	-4.2	-11.9	7.8	-17.8	4.9	-30.4
		L2	T1	-7.6	-6.8	10.4	-9.1	2.5	-14.4	1.0	-5.3
			T2	1.5	-15.3	-1.7	-0.6	15.8	-18.7	4.0	-9.8

(F3-F2)-VALUE FOR CALCULATION OF PITCHING MOMENT AS DEFINED BY HARRISON(12)

APPENDIX NO. 9 (F3-F2)(LB) - REPLICATE NO. 2

S	M	L	T	D1 V1 O1	D1 V1 O2	D1 V2 O1	D1 V2 O2	D2 V1 O1	D2 V1 C2	D2 V2 C1	D2 V2 O2
S1	M1	L1	T1	3.7	-3.7	10.4	-4.6	1.1	-14.9	19.0	-14.7
			T2	-1.3	-12.2	-1.5	-13.8	-2.5	-3.2	-7.5	-11.0
		L2	T1	2.1	-6.2	0.9	-4.9	-7.5	-17.6	-6.7	-9.4
			T2	4.3	-17.2	2.7	-18.5	-0.9	-12.4	7.1	-25.6
	M2	L1	T1	4.7	-6.2	4.4	-11.6	3.6	-12.6	8.3	-18.1
			T2	1.9	-9.4	-3.6	-13.9	-4.4	-13.3	-16.1	-7.9
		L2	T1	6.2	-9.5	-1.1	-9.2	11.6	-13.9	-2.7	-10.9
			T2	6.6	-10.1	-1.3	-16.1	7.0	-9.4	9.5	-12.8
S2	M1	L1	T1	5.5	0.6	18.4	1.4	8.6	2.1	25.8	-19.6
			T2	-7.5	1.8	4.7	-1.6	1.9	-5.3	5.5	-17.6
		L2	T1	-0.9	-3.2	7.8	-18.0	-10.4	-13.3	10.9	-8.8
			T2	-3.8	-4.7	6.7	-18.0	20.1	-23.9	5.4	-17.4
	M2	L1	T1	7.5	-15.9	10.7	-24.1	5.6	-12.4	3.5	-19.0
			T2	1.3	-4.6	18.9	-11.7	4.5	-9.5	5.6	-12.2
		L2	T1	3.5	-5.9	-2.4	-1.8	10.3	-0.6	-1.0	-14.1
			T2	0.4	-10.7	12.5	-13.4	0.1	-3.7	-3.2	-19.4
S3	M1	L1	T1	4.0	-14.4	14.1	-2.2	15.8	-14.2	4.5	-27.0
			T2	-2.8	-12.2	7.5	-4.5	29.3	-16.3	-12.5	-17.6
		L2	T1	-7.6	-9.5	-11.3	-8.2	-10.1	-29.0	-18.3	-34.6
			T2	-17.5	-18.4	-4.3	-8.1	17.8	-34.9	28.8	-14.5
	M2	L1	T1	-14.3	-0.7	28.3	-10.1	-4.0	-16.4	15.9	-19.9
			T2	-2.7	-12.5	20.0	-32.0	0.6	2.9	28.6	-26.9
		L2	T1	13.5	-14.6	6.9	-12.8	-7.6	-14.6	21.0	-14.7
			T2	7.2	-5.2	12.3	-8.0	20.9	-22.5	37.7	-20.5

(F3-F2)-VALUE FOR CALCULATION OF PITCHING MOMENT AS DEFINED BY HARRISON(12)

APPENDIX NO. 9 (F3-F2) (LB) - REPLICATE NO. 3

				D1				D2			
				V1		V2		V1		V2	
S	M	L	T	O1	O2	O1	O2	O1	C2	C1	O2
S1	M1	L1	T1	8.1	-7.1	9.5	-2.9	3.9	0.3	20.9	-8.6
			T2	1.5	-13.0	3.8	-13.7	10.4	-7.4	9.0	-9.6
		L2	T1	-2.6	-14.5	9.1	-15.9	5.5	-13.0	18.3	-17.8
			T2	2.6	-9.3	13.7	-15.9	-4.5	-4.5	5.5	-15.6
	M2	L1	T1	-1.4	1.3	9.1	-11.0	7.5	-9.5	13.6	-8.9
			T2	9.5	-11.1	-5.3	-11.1	1.2	-14.0	2.7	-21.4
		L2	T1	9.1	-14.7	6.2	-4.4	-6.1	-16.8	9.0	-19.0
			T2	5.3	-15.1	-2.1	-8.6	6.0	-8.2	2.3	-20.7
S2	M1	L1	T1	14.6	-5.1	9.7	-18.3	22.6	-8.8	10.4	-18.0
			T2	2.7	-12.9	2.5	-14.3	19.3	-12.1	12.4	-11.9
		L2	T1	-1.2	-12.9	-2.7	-13.6	13.7	-21.7	-2.4	-20.0
			T2	0.5	-2.0	4.9	-18.2	17.4	-19.7	1.3	-40.1
	M2	L1	T1	11.5	-14.7	7.0	-8.0	11.7	-16.1	-25.3	-16.6
			T2	5.4	-25.1	4.2	-9.0	1.4	-14.6	13.6	-18.5
		L2	T1	6.0	-18.2	4.0	-5.8	3.3	-11.0	5.0	-29.2
			T2	15.9	-9.9	7.0	-15.9	22.6	-18.2	14.0	-18.5
S3	M1	L1	T1	5.8	-5.6	4.3	-6.6	10.0	-7.7	18.6	-15.9
			T2	4.7	2.8	7.9	-5.4	13.5	-35.3	4.6	-9.1
		L2	T1	10.6	2.3	-0.4	-12.4	8.1	-14.0	0.7	-9.0
			T2	0.5	-5.3	-2.1	-8.3	10.1	-3.6	18.5	-35.7
	M2	L1	T1	2.2	-9.3	2.8	-6.6	3.0	-4.1	10.5	-11.8
			T2	4.7	-5.8	2.2	-5.4	-13.1	-8.0	3.3	-12.6
		L2	T1	3.2	-0.2	1.9	-10.1	-5.0	-12.7	9.5	-16.9
			T2	0.9	-2.7	5.4	6.9	14.1	-11.0	2.2	-11.9

(F3-F2)-VALUE FOR CALCULATION OF PITCHING MOMENT AS DEFINED BY HARRISON(12)

APPENDIX NO. 10 (F5-F4) (LB) - REPLICATE NO. 1

				D1				D2			
				V1		V2		V1		V2	
S	M	L	T	O1	O2	O1	O2	O1	O2	O1	O2
S1	M1	L1	T1	16.3	-26.2	20.4	-27.0	16.6	-24.9	19.7	-42.3
			T2	31.3	-18.6	8.6	-9.8	25.1	-23.3	1.5	-39.4
		L2	T1	4.8	-12.3	6.5	-31.5	-0.4	-23.4	9.2	-63.7
			T2	16.6	-22.2	2.6	-22.3	23.3	-30.3	12.0	-58.8
	M2	L1	T1	0.6	-25.7	15.8	-12.9	15.3	-24.6	25.4	-8.3
			T2	-3.6	-11.5	4.6	-11.4	5.6	-26.0	30.0	-46.0
		L2	T1	-8.7	-20.3	14.0	-9.3	2.8	-14.7	7.6	-30.7
			T2	1.3	-19.3	14.1	-16.6	1.7	-30.3	27.0	-33.9
S2	M1	L1	T1	23.8	-18.0	2.7	0.7	13.1	-27.6	10.5	-38.9
			T2	15.0	-28.0	27.8	-14.7	25.1	-17.7	21.2	-60.2
		L2	T1	33.0	-13.3	-8.9	-35.1	44.7	-29.4	2.7	-49.9
			T2	10.2	-21.4	4.1	-19.9	10.0	-26.1	47.0	-49.2
	M2	L1	T1	11.6	-30.2	5.0	-25.5	8.9	-36.3	21.5	-49.9
			T2	21.4	-5.4	9.0	-19.5	14.8	-32.4	42.4	-52.7
		L2	T1	16.8	-13.9	-8.2	-28.2	34.1	-35.9	5.1	-49.5
			T2	7.6	-16.6	32.1	4.8	34.1	-41.3	31.6	-30.6
S3	M1	L1	T1	-3.9	-22.9	-1.8	-28.9	8.1	-9.4	-3.7	-18.6
			T2	11.6	-15.7	19.6	-30.6	26.2	-40.0	17.6	-59.4
		L2	T1	-0.9	-9.1	9.6	-18.8	4.1	-19.3	45.2	-33.7
			T2	28.0	-18.3	9.8	-47.2	39.4	-42.8	3.9	-5.2
	M2	L1	T1	5.2	-16.6	13.5	-33.4	32.8	-36.7	14.5	-39.1
			T2	8.8	-16.2	-2.5	-21.0	24.7	-33.6	24.0	-59.4
		L2	T1	-7.8	-13.9	18.7	-18.5	7.9	-28.2	11.0	-18.3
			T2	7.8	-26.7	2.3	-30.2	40.4	-35.8	16.0	-19.5

(F5-F4)-VALUE FOR CALCULATION OF PITCHING MOMENT AS DEFINED BY HARRISON(12)

APPENDIX NO. 10 (F5-F4) (LB) - REPLICATE NO. 2

				D1				D2			
				V1		V2		V1		V2	
S	M	L	T	O1	O2	O1	O2	O1	O2	O1	O2
S1	M1	L1	T1	6.0	-8.4	21.1	-10.7	7.1	-29.3	45.8	-32.1
			T2	2.7	-17.5	3.2	-23.1	4.5	-4.4	-3.9	-24.5
		L2	T1	11.1	-8.2	15.4	-9.4	2.9	-29.1	4.2	-11.4
			T2	17.7	-20.9	13.4	-24.6	5.5	-19.9	27.2	-45.9
	M2	L1	T1	7.3	-11.1	10.6	-19.1	13.3	-26.4	21.4	-36.6
			T2	9.1	-14.7	-6.2	-27.1	0.7	-22.1	-28.8	-16.9
		L2	T1	12.0	-15.7	4.5	-14.8	23.7	-26.4	0.0	-22.4
			T2	16.6	-16.8	5.6	-28.1	22.5	-15.3	29.8	-26.2
S2	M1	L1	T1	14.6	3.5	40.6	5.1	21.9	3.8	58.2	-37.9
			T2	-0.3	6.8	18.9	0.4	16.0	-5.9	24.9	-32.8
		L2	T1	9.1	2.1	33.1	-20.0	8.8	-13.8	37.7	-5.0
			T2	12.1	6.1	26.9	-22.1	50.7	-36.9	27.6	-24.6
	M2	L1	T1	20.7	-25.6	20.9	-38.7	17.7	-22.7	15.0	-36.0
			T2	10.3	-0.3	39.2	-10.4	22.9	-12.3	31.1	-20.7
		L2	T1	10.9	-5.3	10.5	6.0	24.8	2.3	6.9	-24.1
			T2	7.4	-17.1	27.3	-22.6	13.9	-2.6	10.3	-32.7
S3	M1	L1	T1	7.1	-18.4	25.3	-7.4	26.9	-43.9	18.6	-56.8
			T2	8.9	-27.1	15.1	-8.8	59.2	-16.9	11.3	-31.7
		L2	T1	7.5	-6.3	-19.7	-14.8	-8.3	-66.3	-19.7	-69.0
			T2	-7.8	-24.1	3.4	1.0	38.9	-54.3	49.6	-35.8
	M2	L1	T1	-11.4	-5.9	54.7	-23.2	-9.4	-42.0	47.3	-32.2
			T2	0.4	-25.4	43.2	-44.3	1.0	3.9	61.6	-56.2
		L2	T1	28.6	-16.0	14.7	-30.2	-7.4	-26.3	40.0	-36.8
			T2	18.3	-10.4	23.8	-20.1	36.6	-42.2	78.6	-50.5

(F5-F4)-VALUE FOR CALCULATION OF PITCHING MOMENT AS DEFINED BY HARRISON(12)

APPENDIX NO. 10 (F5-F4) (LB) - REPLICATE NO. 3

				D1				D2			
				V1		V2		V1		V2	
S	M	L	T	01	02	01	02	01	02	01	02
S1	M1	L1	T1	18.2	-11.7	22.4	-6.9	12.3	-12.6	45.2	-16.8
			T2	9.9	-13.9	1.4	-16.8	24.0	-29.5	30.1	-15.1
		L2	T1	8.3	-16.0	29.0	-21.1	28.5	-15.7	51.6	-25.4
			T2	15.5	-10.3	37.6	-19.9	11.3	-4.7	29.9	-22.5
	M2	L1	T1	4.5	1.7	20.4	-16.6	18.4	-19.5	29.6	-10.0
			T2	22.8	-14.6	2.6	-10.5	14.8	-18.8	15.7	-31.3
		L2	T1	15.0	-21.8	15.7	-5.5	-0.2	-27.8	27.7	-34.8
			T2	17.5	-23.9	7.0	-8.1	27.0	-10.9	20.2	-35.3
S2	M1	L1	T1	27.9	-9.6	24.7	-28.3	44.3	-16.7	28.9	-43.6
			T2	19.0	-15.6	18.5	-20.8	50.8	-22.4	32.5	-23.4
		L2	T1	17.7	-21.6	25.5	-12.7	38.5	-30.7	26.3	-28.2
			T2	18.8	13.0	34.6	-20.6	44.9	-30.5	20.9	-64.1
	M2	L1	T1	29.0	-19.9	19.8	-15.9	30.2	-29.9	-49.8	-36.4
			T2	32.2	-38.6	23.3	-12.7	21.6	-29.5	38.3	-32.3
		L2	T1	17.0	-30.3	32.5	-14.1	18.0	-27.8	24.3	-42.5
			T2	42.4	-11.0	29.7	-25.3	51.6	-32.7	35.8	-30.1
S3	M1	L1	T1	15.4	-14.0	16.8	-3.1	32.7	-5.4	52.8	-22.5
			T2	18.7	10.3	19.1	1.8	45.9	-51.6	32.1	2.1
		L2	T1	33.7	9.6	31.3	2.7	39.2	-8.6	40.0	-8.7
			T2	21.9	3.9	10.2	4.7	51.9	7.1	64.8	-24.4
	M2	L1	T1	14.0	-5.4	22.8	-2.6	15.0	-8.3	34.6	-18.5
			T2	25.1	11.7	24.7	4.3	15.5	-11.6	29.1	-10.7
		L2	T1	14.9	8.1	15.0	-5.9	17.3	-9.4	37.5	-8.2
			T2	18.0	3.9	27.9	23.4	35.9	-5.0	30.3	-9.7

(F5-F4)-VALUE FOR CALCULATION OF PITCHING MOMENT AS DEFINED BY HARRISON(12)